MASTER OF SCIENCE BY RESEARCH

The effect of acclimation and habituation to wearing an Explosives Ordnance Disposal (EOD) suit on heat strain in moderate and hot conditions

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Award date:
2009

Awarding institution:
Coventry University

The Effect of Acclimation and Habituation to Wearing an Explosives Ordnance Disposal (EOD) Suit on Heat Strain in Moderate and Hot Conditions.

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A thesis submitted in partial fulfilment of the University's requirements for the degree of Master of Science (by Research) in Applied Physiology

Submitted February 2009

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ABSTRACT

Purpose: The aim of the study was to evaluate the impact of acclimation / habituation on thermal, metabolic and perceptual responses to conducting bomb disposal related activity with and without wearing an Explosive Ordnance Disposal (EOD) suit in a moderate (20°) and a hot (40°C) environment.

Methods: With ethical approval from Coventry University Ethics Committee 5 male and 1 female non heat acclimated participants completed the investigation. Four experimental trials were conducted over an 8 day period both before and after an acclimation / habituation period (6 acclimation / habituation sessions whilst wearing the EOD suit for 60 min treadmill walking at 4 $km \cdot hr^{-1}$ in 21.6±1.2°C, 47.0±5.4% RH completed over 9 days; 2 days on 1 day off pattern; the internal fan system was switched off throughout). Within each experimental trial participants completed a 66 min EOD related activity sequence (Thake and Price 2007) that was modified to standardise work rate. In the first and third trials basic military clothing was worn (no suit trials; NS) and the EOD bomb disposal suit, with its internal fan system switched on, was worn in the second and fourth trials (EOD trials). Ambient temperature (20° or 40°C) was applied to these trials using a cross-over type design.

Results: Acclimation / habituation reduced (P<0.05) T_C (°C), heat storage, HR, $\dot{V}O_2$, $\dot{V}E$, physiological strain, RPE, thermal sensation, thermal comfort and perceptual strain when the EOD suit was worn in both 20° and 40°C trials compared to PRE acclimation / habituation measurements. No change in mean sweat rate was induced and T_{SK} was not reduced in 40°C but declined (P<0.001) in 20°C. The magnitude of reduction was greatest in the 20°C EOD versus 40°C EOD. All participants completed PRE and POST 20°C EOD trials and tolerance increased from 53:48±11.59 (min:sec) to 60:10±09:34 (min:sec) in 40°C EOD following acclimation / habituation. Acclimation / habituation also reduced (P<0.05) T_C, HR, $\dot{V}O_2$, thermal sensation, thermal comfort and perceptual strain in 20°C and 40°C NS trials. Again no change in mean sweat rate was induced by acclimation / habituation in either NS trials. However lower T_{SK}, physiological strain and RPE values were noted in 20°C NS POST trials and lower heat storage and $\dot{V}E$ values were found in 40°C NS POST trials compared to PRE acclimation / habituation measurements.

Conclusion: Six one hour acclimation / habituation sessions of wearing the EOD suit whilst walking at 4 km·hr $^{-1}$ at an ambient temperature of 21.6±1.2°C, 47.0±5.4% RH induced beneficial thermal, metabolic and perceptual changes that are evident when conducting EOD related activities in both temperate and hot conditions. Such adaptations are likely to be associated with improved work capacity and an improved ability to maintain operational effectiveness.

ACKNOWLEDGEMENTS

I would firstly like to convey my gratitude to Dr Doug Thake for his time and supervision during my postgraduate research degree. His guidance during this period has been extremely insightful and is a key factor contributing towards the completion of this thesis and my continuing interest in research.

I would also like to thank the university's laboratory technicians, Mr Roy Petticrew and Mrs Susan Wilson, as well as Debbie Shuttleworth, Lewis Samson and Mark Smith for their support and assistance during data collection.

Additionally I would like to thank all of the participants involved in the study whose commitment and hard work is extremely appreciated.

Finally I would like to thank my close family and friends for their tireless support during my degree. Without this completing this thesis would have been extremely difficult. For that I am deeply grateful.

APPENDICIES **112**

ABBREVATIONS

20 EOD – Explosives Ordnance Disposal worn in 20°C environment

40 EOD - Explosives Ordnance Disposal worn in 40°C environment

20 NS – No Suit worn in 20°C environment

40 NS - No Suit worn in 20°C environment

PRE – Data from Experimental Trials Prior to Acclimation

POST – Data from Experimental Trials Following Acclimation

UHS – Uncompensable Heat Stress

PPE – Personal Protective Equipment

ANOVA – Analysis of Variance

n – Number of Participants / Data Points

RH – Relative Humidity

T_C – Core Temperature

T_{SK} – Mean Skin Temperature

HR – Heart Rate

$\dot{V}E$ – Minute Ventilation

$\dot{V}O_2$ – Oxygen Consumption

$\dot{V}O_{2peak}$ – Peak / Maximal Oxygen Consumption

STPD – Standard Temperature and Pressure Dry

RPE – Rating of Perceived Exertion

GSQ – General Symptoms Questionnaire

PSI – Physiological Strain Index

PhSI – Adapted Physiological Strain Index

PeSI – Perceptual Strain Index

1 INTRODUCTION

Physical activity in a hot environment leads to heat storage and heat strain when the magnitude of heat generation exceeds the evaporative capacity of the environment. Exercise increases metabolic heat production and a hot environment with a large relative humidity (RH) impairs the heat loss pathways (conductive, convective, radiant and evaporative) between the body and the surrounding atmosphere (Cheung, McLellan and Tenaglia 2000). As heat strain rises the body is increasingly unable to maintain core temperature (T_C) at the predetermined level, set by the hypothalamus, with a consequent reduction in physiological and cognitive performance.

In various occupational or sports settings it is essential for participants to wear forms of personal protective equipment (PPE) to defend from physical hazards. Physical activity in PPE only serves to exacerbate the problems of heat storage and generally increases physical strain. The garments worn for protection are often limited in their water vapour permeability (Cheung, McLellan and Tenaglia 2000) particularly so with forms of military body armour resulting in a saturated microenvironment between the skin and the clothing.

The physiological and psychological problems associated with heat strain will occur much more rapidly if physical activity in PPE occurs in high ambient temperatures and will result in reduced heat tolerance time (Thake and Price 2007). In these conditions of uncompensable heat stress (UHS; defined as when the amount of evaporative cooling required to reduce heat storage exceeds the evaporative capacity of the environment) the body will store heat, ultimately elevating T_C often to dangerous levels due to the limited evaporative capacity of the microenvironment surrounding the skin (Cheung, McLellan and Tenaglia 2000). Physical activity in hot conditions also augment increases in HR, heat storage, skin temperature (T_{SK}) (Aoyagi, McLellan and Shephard 1995), perceived exertion and thermal discomfort (Aoyagi, McLellan and Shephard 1998) as well as a impairing cognition (Radakovic, Maric, Surbatovic *et al.* 2007).

Many interventions have been developed and investigated that aim to reduce heat strain and therefore maintain operational effectiveness and safety (Young, Sawka, Epstein *et al.* 1987). For instance Vallerand, Michas, Frim *et al.* (1991) assessed the different capabilities of an air cooled compared to a liquid cooled vest worn under PPE in reducing heat strain. Thake and Price (2007) compared different equipment configurations of an EOD bomb disposal suit when a laboratory based activity related to bomb disposal activities was completed. They report that when a lighter trouser configuration was worn in 40°C not only was T_C reduced compared to a heavier trouser but participants reported that mobility increased which improved their ability to conduct set tasks.

More traditional methods of reducing heat strain experienced by individuals in challenging environment is through the completion of physical training programmes and / or through manipulating an individual's hydration status (Cheung and McLellan 1998a) or body temperature (Frim and Morris 1991) to increase a participant's heat storage capacity. Previous research has shown long term physical / aerobic training, that improves the participant's oxygen consumption capability, will allow them to tolerate a higher T_C at exhaustion (Selkirk and McLellan 2001; Pandolf 1979). This change will only occur if the participant undertakes a training programme, with sessions of sufficient intensity, duration and length that elevates T_C and HR.

Another method of increasing an individual's exercise capability in the heat is through the completion of a period of artificial heat acclimation. This intervention requires participants to be repeatedly exposed to heat to instigate advantageous physiological and psychological changes that increase heat tolerance. Acclimation is known to decrease T_C, HR, T_{SK} and heat storage levels at given exercise intensities (Gill and Sleivert 2001). It can also decrease the negative perceptions associated with the heat through an improvement in heat dissipation efficiency caused by an increase sweat rate (Nadel, Pandolf, Roberts *et al.* 1974) that is supported by an increase in plasma volume (Senay, Mitchell and Wyndham 1976).

Acclimation programmes are widely used in the sports community (Sunderland, Morris and Nevill 2008) and more recently are being employed by industrial personnel to decrease the energy cost for given tasks (Aoyagi, McLellan and Shephard 1997). However few alterations are made to the protocol to account for the increase in heat storage that encapsulating clothing ensembles, such as an EOD suit cause. It is reported that larger beneficial physiological and psychological changes occur when the PPE is worn during heat acclimation sessions (McLellan and Aoyagi 1996). This allows individuals to become habituated to the psychological discomforts associated with it and decrease the relative intensity of tasks, reducing oxygen consumption (Shvartz, Saar, Meyerstein *et al.* 1973) and therefore metabolic heat production. It is not known to what extent these changes occur when work related tasks are completed in a temperate and hot environment. Such information has the potential to make operational recommendations to increase safety and working effectiveness when the clothing ensemble is worn in the field.

1:1 Aim

1. To investigate the magnitude of thermal strain (physiological and psychological variables) when wearing an EOD suit and completing a bomb disposal related activity in 20° and 40°C.
2. To assess the impact of acclimation / habituation on thermal strain (physiological and psychological variables) when wearing an EOD suit and completing a bomb disposal related activity in 20° and 40°C.

1:3 Hypothesis

Acclimation / habituation will reduce thermal, metabolic and perceptual responses to a simulated bomb disposal activity sequence in both a moderate (20°C) and a hot (40°C) environment, with and without wearing an EOD suit.

2 LITERATURE REVIEW

2:1 Basic Principles of Heat Transfer

Exercise increases metabolic rate and therefore the amount of heat produced. This heat needs to be removed from the body to maintain a thermal steady state and avoid the detrimental side effects of an undesirable increase in T_C. There are four ways that this can occur. When body temperature is higher than that of the surrounding environment radiant heat loss occurs through the air to cooler objects in the environment. Heat can also be dissipated through the warming of air molecules by the skin surface (conduction) this cooling mechanism is however dependent on the speed of air movement around the body (convection). The final and most efficient method of cooling is via evaporation from skin surface and respiratory tract (Havenith 1999).

When the body is encapsulated the temperature of the surrounding air between the skin surface and clothing layer increases and its movement around the body is reduced. Radiant, conductive and convective heat loss pathways now contribute to heat gain via heat absorption and insulation of the air around the body meaning that sweat evaporation and water vaporisation is the only avenue for heat dissipation (Wenger 1972). Obviously when the body is fully encapsulated the heat transfer gradient is severely reduced as little or no skin is in contact with the ambient surroundings due to this skin temperature increases to similar values as T_C. The RH of the microenvironment PPE creates is high, reducing the potential of heat dissipation due to the similarity in vapour pressure of the air and the skin surface when it is moist

(Havenith 1999). In this case sweat will accumulate on the skin surface and not evaporate. This severely restricted avenue for heat loss results in uncompensable heat stress (UHS), this increases physiological strain and is associated with psychological discomfort (Cheung, McLellan and Tenaglia 2000).

2:2 Examples of Occupational Research

The term PPE encompasses many different clothing ensembles from various sporting and occupational settings. The common 'trade-off' being, increased protection compromises heat transfer and increases metabolic heat production. The rate of cooling needed to maintain the thermal steady state is reduced which results in heat storage (Cheung, McLellan and Tenaglia 2000). PPE forms a microenvironment between the body and the ambient surroundings that heat must pass through before it can be dissipated (Sullivan and Mekjavic 1992), heat that is not dissipated is stored.

The ambient and microenvironment temperature has an inverse relationship with work tolerance time. Cortili, Mognoni and Saibene (1996) measured the microenvironment temperature during 120 min cycle ergometry (60 W) exercise in environmental temperatures of minus 20° to plus 35°C (20 to 85% relative humidity; RH) when a ventilated nuclear, biological and chemical (NBC) suit was worn. They suggested that during heat exposure the microenvironment temperature is a good indicator of thermal load as work duration steadily declines when this temperature, which has a strong correlation with the ambient temperature, increases in excess of 30°C.

Increasing the encapsulation level and number of clothing layers of PPE increases metabolic heat production and decreases physical tolerance to the heat because of the weight of the clothing and the difficulty of moving in it (Cheung, McLellan and Tenaglia 2000). For example tolerance to an elevated T_C in a desert environment is lower when the clothing ensemble fully encapsulates (38.5°±0.6°C) the participant compared to when it partially (39.1°±0.6°C) encapsulates in part due to the reduction in the thermal gradient when the fully encapsulating clothing was worn (Montain, Sawka, Cadarette *et al.* 1994). Also moderate work in a 37°C environment decreased work tolerance (defined as T_C rise to 38.5°C) from 90 min, in a single layered garment to 20 min in a fully encapsulated impermeable ensemble (Havenith 1999). Furthermore, Sullivan and Mekjavic (1992) used four examples of helicopter personnel suits, each with differing liquid and water vapour transmission properties in increasing ambient temperatures ranging from 20° to 40°C and found that only one of the suits, which was impermeable and completely encapsulated participants, increased T_C (by 1.21°C) over a 180 min period. Results indicated that this occurred because the vapour pressure of the 8 mm microenvironment in this condition was higher than that of the ambient surroundings (5.68 compared to 2.06 kPa) which would reduce heat loss and increase the amount of sweat that is absorbed by the suit (Cheung, McLellan and Tenaglia 2000).

Chemical protective (CP) clothing is designed to protect the wearer from chemical agents while subjecting them to low levels of heat strain due to its permeable configuration. Patton, Bidwell, Murphy *et al.* (1995) investigated the energy cost of three different configurations of increasing encapsulation during an incremental treadmill test (1.56 $m \cdot s^{-1}$ for 20 min each at 0, 5 and 10% gradients). They attributed the small increases in $\dot{V}O_2$ (13-18%) seen between the lowest and highest clothing conditions to the increased difficulty of movement and the weight of the clothing. However these trends are only seen in exercise intensities up to 60% $\dot{V}O_{2peak}$ and exercise was performed in a temperate condition so it can be assumed that these conditions did not affect the maintenance of the thermal steady state.

A fully encapsulating example of PPE is an NBC suit. In addition to the standard operational undergarments NBC clothing is 8 kg in mass and consists of a respirator, a semipermeable overgarment and impermeable boots and gloves (Aoyagi, McLellan and Shephard 1994). This means that heat strain is high and tolerance times are reduced (White, Hodous and Vercruyssen 1991) even when ambient temperatures are low. A walking protocol in NBC clothing of varying intensities (341 to 680W) in ambient temperatures of as low as minus 33°C still increased T_C in excess of 38°C (Rissanen and Rintamaki 2007). Again as seen with all other PPE when the weight and/or volume of encapsulation increases or at greater exercise intensities tolerance time will decrease (McLellan 1993).

Another example of a fully encapsulating piece of PPE is a bomb disposal suit. The extent of the increase in thermal strain that physical activity elicits when this clothing ensemble is worn is of particular interest due to its large mass (37 kg; Thake and Price 2007). Thake and Price (2007) used an Explosives Ordnance Disposal (EOD) suit (> 35 kg in mass) in 40°C to evaluate thermal strain during an EOD related laboratory based activity sequence. Although this study had a small sample size (n=4) they found that activities increased T_C. Also if exercise was completed when the participants wore a lighter weight trouser, to improve mobility, T_C was reduced and if a dry ice device was integrated into the ensemble mean skin temperature (T_{SK}) was reduced, indicating a decline in heat storage.

2:3 Physiological Responses to Exercise in the Heat and PPE

When physical activity in the heat is undertaken both T_C and T_{SK} increase to dissipate metabolic heat. To maintain the temperature gradient and dissipate heat effectively T_{SK} increases rapidly and increases in T_C are relatively slow. If PPE is worn in this environment increases in temperatures are intensified due to an elevation in metabolic rate caused by the thermal properties and mass of the clothing. An elevated metabolic cost (13%) was found when participants wore an NBC ensemble over combat clothing in 40°C, 30% RH during treadmill walking (4.8 $km.hr^{-1}$, 2% gradient) compared to when only combat clothing was worn during the activity under the same conditions (Aoyagi, McLellan and Shephard 1994).

In UHS conditions T_{SK} increases in an attempt to cool the body via radiant, conductive, convective and evaporative pathways. This is why an increase in T_{SK} is a good indicator of a UHS. Where ambient and skin temperatures are similar (reduced core to skin thermal gradient) this is severely limited which heats up the body from the skin surface as the evaporative efficiency decreases due to the microenvironment PPE creates (Cheung, McLellan and Tenaglia 2000). Heat that is not dissipated is stored increasing T_C which potentially could incapacitate an individual if it exceeds between 39-40°C dependent on the individual's resting value (Latzka, Sawka, Montain *et al.* 1998). Over a 66 min bomb disposal related activity sequence at 40.5±1.1°C Thake and Price (2007) also observed that due to the mass of load carried and thermoregulatory needs HR, which is another marker of physiological strain, increased when participants wore an EOD suit compared to when a considerably lighter sports clothing ensemble was worn.

Latzka, Sawka, Montain *et al.* (1998) even observed that once final T_C exceeded 38°C during treadmill walking in chemical protective clothing at 34.9±0.1°C physical characteristics of heat strain such as a lack of muscular coordination, fatigue and faintness are reported and as T_C recorded at physical exhaustion increases further these symptoms appear more frequently. To avoid the occurrence of these symptoms during experimental tests predetermined T_C safety parameters are set. Montain, Sawka, Cadarette *et al.* (1994) set this value at 40°C when participants conducted a treadmill walking (425 W and 600 W) protocol while wearing full (trousers, coat, overboots gloves and facemask with hood) or partial (trousers and coat) protective clothing in two environments (43°C, 20% RH and 35°C 50% RH). However these limits were not exceeded in these conditions even when physical tolerance was reached.

At higher stress levels (50 min walking in 49°C, 20% RH in a semipermeable ensemble) Pandolf and Goldman (1978) suggest that a convergence of T_C and T_{SK} is more practical as a limit for tolerance as it links closely with participants perceptions of perceived exertion and thermal discomfort. This could be because PPE increases the relative intensity of exercise. More heat is produced which causes temperature and water vapour pressure variations to have less of an effect on tolerance times (Cheung, McLellan and Tenaglia 2000). A way of ensuring these variations have more of an effect is to introduce intermittent exercise or rest periods into research (McLellan, Jacobs and Bain 1993).

As PPE increases physiological strain one would expect an increase in sweat production to occur in order to dissipate the additional heat produced via sweat evaporation from the skin surface. However a vast quantity of sweat is absorbed and trapped by PPE, since wet heat transfer is restricted. Aoyagi, McLellan and Shephard (1998) reiterate this reporting that an NBC garment increased sweat production (from 0.81±0.06 to 1.12±0.10 $kg \cdot hr^{-1}$) and sweat accumulation in the clothing microenvironment (from 0.19±0.03 to 0.79±0.10 $kg \cdot hr^{-1}$) compared to when participants wore light military clothing during treadmill walking (1.34 $m \cdot s^{-1}$, 2% gradient) in 40°C, 30% RH for 120 min or until volitional exhaustion. But sweat evaporation from the skin surface was reduced (from 0.62±0.04 to 0.33±0.01 $kg \cdot hr^{-1}$) in the NBC clothing meaning that more of it was absorbed by the clothing. This was thought to decrease psychological discomfort due to a reduced perception of a moist / wet microenvironment.

When the body sweats it can cause a water deficit a condition known as hypohydration (Cheung, McLellan and Tenaglia 2000). This decrease in hydration status means that an individual is less capable of exercising and reduces heat tolerance time. Cheung and McLellan (1998a) reported that ≈ 2.5% hypohydration, measured by a reduction in body mass caused an increase in the initial rise in T_C, HR and decreased tolerance time to treadmill walking when an NBC suit was worn in 40°C, 30% RH. These changes were independent of acclimation status and show that even a minor hypohydration level impairs tolerance to UHS conditions (Cheung and

McLellan 1998b) due to the progressive decreases in evaporative heat exchange and the capacity of the body to absorb heat. In a graded hypohydration investigation of 3, 5 and 7% of body mass Sawka, Young, Francesconi *et al.* (1985) observed that T_C and HR responses intensified and sweat response for a given T_C deteriorated as the severity of hypohydration increased during four repeated 25 min treadmill walking (1.34 $m \cdot s^{-1}$) bouts in a hot-dry environment (49°C, 20% RH). One issue with this study is that it was conducted when PPE was not worn, however the protocol was conducted in a UHS environment as the ambient temperature exceeded an average T_{SK} of 33°C by 16°C.

A long established method of increasing exercise heat tolerance is to manipulate hydration status to avoid hypohydration. Fluid levels need to be maintained during exercise in UHS conditions to aid cardiovascular and thermoregulatory homeostasis and to preserve plasma volume to offset an increase in sweating (Candas, Libert, Brandenberger *et al.* 1986). When the volume of circulating blood decreases the competition between metabolic and thermoregulatory demands intensifies (Rowell 1974) leading to a decrease in peripheral blood flow because the T_C threshold for vasodilatation rises (Cheung, McLellan and Tenaglia 2000). A decline in total blood volume also impairs the sweat response further limiting heat transfer leading to a greater T_C. Fluid ingestion is however difficult during such operational activities as carried out by EOD operative due to the PPE worn and the short work duration.

Considerations that need to be accounted for when replacing fluid is the amount ingested, as too much could lead to gastric discomfort, and the time it takes for ingested fluid to be emptied from the stomach. Thermal strain limits this rate as it shifts blood flow away from the stomach to the periphery (Cheung, McLellan and Tenaglia 2000). When PPE is worn in hot environments fluid replacement only rehydrates if the exercising intensity is low. However Lee, Shirreffs and Maughan (2008) report that when exercise (cycle ergometry; 65% $\dot{V}O_{2peak}$) is conducted in the heat (35°C, 60% RH) when PPE was not worn cold water (4°C) ingestion has been found to increase heat storage capacity, seen via a reduction in T_C (0.5°C) prior to the commencement of exercise, compared to warm water (37°C) ingestion. Also HR, T_{SK}, RPE (14±1 compared to 15±1) and thermal sensation (5±1 compared to 6±1) were lower during exercise following cold water ingestion compared to warm water ingestion. Sweat rate (1.22 l·hr $^{-1}$ compared to 1.40 l·hr $^{-1}$) was also reduced and exercise time increased (63.8 compared to 52 min) when cold water was ingested.

Conflict appears over establishing a viable method of measuring heat storage. Traditionally equations using relative weightings for T_C and T_{SK} (4:1) have been used however Aoyagi, McLellan and Shephard (1996) report that when PPE was worn this method overestimated heat storage, compared to calorimetric estimates, by 2-12% due to T_{SK} rising close to T_C values. They suggested that the accuracy of the equations could be improved by modifying the weightings to consider the clothing type, environment or the individual's acclimation status. Nunneley (1989) also states that models of prediction need to represent the interactions of heat stress factors (e.g. weight and stiffness of PPE) and physiological variables (e.g. $\dot{V}O_{2peak}$).

2:3:1 Physiological Strain Indices:

More recently Moran, Shitzer and Pandolf (1998) developed a physiological strain index (PSI) which normalised increases in T_C and HR and rated physiological strain on a 0 (no strain) - 10 (very high strain) scale. Calculations only use two variables which decrease the source of error and means that physiological strain can easily be established in real time. Using data acquired by Montain, Sawka, Cadarette *et al.* (1994), to calculate PSI, it was observed that this scale was differentiated between treadmill exercise that was completed in a hot-wet (35°C, 50% RH) and a hot-dry (43°C, 20% RH) environment when protective clothing (trousers, coat, overboots gloves and facemask with hood) was worn. This is now a widely accepted measure of exercise-heat strain. It does however limit increases in heat storage and physical exertion depicted as a T_C increase to 39.5°C and a HR increases to 180 bt·min^{-1}.

Tikuisis, McLellan and Selkirk (2002) considered these factors and developed the PhSI index, which replaced resting HR with a standard value of 60 bt·min^{-1} and the participants actual HR_{max} giving a more participant specific calculation. They also developed a perceptual strain index (PeSI) alongside the PhSI which was calculated through normalising increases in RPE and thermal sensation and again rated strain on a 0-10 scale. When validating these indexes they discovered that trained participants underestimated their perceptual strain in relation to their physiological strain during treadmill walking (3.5 km·hr^{-1}) in the heat (40°C, 30% RH) when wearing semi-permeable protective clothing. To accommodate for this difference it was suggested that adapting the maximum T_C value in the equation to match a level that could be achieved by the specific individual as it has been shown that individuals with a greater aerobic capacity (65 ml·kg·LBM^{-1}·min^{-1} compared to 53 ml·kg·LBM^{-1}·min^{-1}) are capable of tolerating a higher T_C (39.48±0.01°C compared to 38.58±0.19°C) at exhaustion (Selkirk and McLellan 2001) due to heat protective physiological adaptations (Tikuisis, McLellan and Selkirk 2002). Altering the equation would eliminate the variability in T_C that can be achieved by an individual within a population of differing aerobic capacities. However establishing a specific value for each individual would be extremely difficult.

It has also been reported that thirty-seven fire-fighters wearing their full protective clothing ensemble and self-contained breathing apparatus while completing treadmill exercise at four different intensities underestimate physiological strain. Selkirk and McLellan (2003) observed this at exhaustion when exercise was completed in a 25°C, 50 RH (PhSI; 6.80±0.77, PeSI; 5.78±1.62) and a 30°C, 50%RH (PhSI; 6.96±0.72, PeSI; 5.94±1.59) environment. This potentially suggests that operatives who regularly wear the clothing ensemble become accustomed to the physiological demands and perceptual discomfort of it.

Other variables that are considered to have an influence on heat strain is the effect of the individual's $\dot{V}O_{2peak}$ and the increase in %$\dot{V}O_{2peak}$ participants exercise at in UHS conditions. Physical activity in PPE increases %$\dot{V}O_{2peak}$ and energy cost, intensifying HR and temperature changes. Cheung and McLellan (1999a) demonstrated that %$\dot{V}O_{2peak}$ was the strongest predictor of heat strain when participant's wore NBC clothing at a fixed ambient temperature (40°C, 30% RH) and performed treadmill exercise (3.5 km·hr^{-1}). An increase in energy cost is also seen when PPE is worn during exercise in colder ambient surroundings. During a bench stepping task at 10°C $\dot{V}O_2$ increased by 9% (from 1.85 $L{\cdot}min^{-1}$ to 2.13 $L{\cdot}min^{-1}$) when a multiple layered piece of PPE was worn compared to when military combat clothing was worn (Duggan 1988). This increase in energy cost reduced the time to the onset of fatigue due to an increase in metabolic heat production.

2:4 Perceptual Responses to Exercise in Heat and PPE

Increased of heat strain also influences the participant's perceptions. When T_C and sweat rate increase so does perceived exertion (RPE; Borg 1970), thermal sensation (Young, Sawka, Epstein *et al.* 1987) and thermal comfort (Epstein and Moran 2006). High values in perceptual heat strain variables are associated with impaired cognition, as measured by tests of reaction time and rapid visual information processing (Radakovic, Maric, Surbatovic *et al.* 2007), and limit heat tolerance time (McLellan and Cheung 2000).

As with physiological variables, the more encapsulated an individual is the more susceptible they are to perceptual strain. For example perception of heat has been reported to be higher when a three-piece chemical protective ensemble was worn in three different thermal environments (10.6°, 22.6° and 34°C) during an intermittent 120 min treadmill walking (4 $km{\cdot}hr^{-1}$) protocol. Rating of perceived work and temperature in the clothing were highest in the hot environment (perceived work; 5.4±0.6, temperature in clothing; 6.2±0.2; based on 7-point scales) with this ensemble compared to when a light clothing garment was worn (perceived work; 3.4±0.6, temperature in clothing; 4.6±0.2) (White, Hodous and Vercruyssen 1991).

Perceived exertion (Borg 1974) and thermal sensation (Young, Sawka, Epstein *et al.* 1987) values are dependent on the physical status of the individual. However if they under perceive heat strain they may continue to exercise when their T_C reaches dangerous levels (over 40°C). The PeSI (explained in Section 2:3:1) has also been shown to increase when dehydrated participants completed a treadmill walking (3 $km \cdot hr^{-1}$) and rifle marksmanship protocol in 28-30°C while 42°C water was circulated round a Canadian forces NBC suit to ensure a steady rise in T_C compared to when room temperature water was fed into the suit during the same protocol (Tikuisis and Keefe 2005). Another method that has been discussed to reduce perceptions of heat is an acclimation period where PPE is worn in the heat (Section 2:5:1). However this has been shown to have no effect, due to the limited sweat evaporation from the skin surface in a NBC suit (Aoyagi, McLellan and Shephard 1998).

An elevated T_C also severely affects aspects of cognition but assessing the specific changes and cross validating results is difficult due to the range of tasks investigated. Considerations that need to be addressed when incorporating cognition tests are the task type, the exposure duration and the skill and acclimation status of the participants (Hancock and Vasmatzidis 2003). During a seven hour exposure completing military tasks (map-plotting) in 32.8°C while wearing chemical protective clothing saw a reduced productivity of 40% compared to control conditions even though the accuracy was unaffected (Fine and Kobrick 1987). Radakovic, Maric, Surbatovic *et al.* (2007) incorporated a cognition test (Cambridge Neuropsychological Test Automated Battery) into heat-stress trials (treadmill walking, 5.5 $km \cdot hr^{-1}$ in 40°C) and found that individuals were more capable of maintaining attention following a 10 day acclimation period (1 hour treadmill walking, 5.5 $km \cdot hr^{-1}$). They also saw that heat stress tests decreased the number of correct responses (from 79.4±7.1% to 69.7±10.3%) to a rapid visual information processing test.

2:5 Interventions to Reduce Heat Strain in Heat and PPE

Many interventions have been developed to alleviate the physiological and psychological stress associated with heat strain with a view to improve operational effectiveness and safety. Recent occupational advancements in this area include the integration of cooling devices and altering garment arrangements to either reduce the mass of the ensemble (Thake and Price 2007) or increase evaporative efficiency. More traditional methods include improving the participant's aerobic fitness and / or manipulating their hydration status to facilitate a greater amount of heat storage (Section 2:3).

To reduce the microenvironment temperature many different methods have been investigated. Examples include either liquid or air cooled systems or the use of a phase change material. Young, Sawka, Epstein *et al.* (1987) tested a liquid microclimate system worn under combat clothing and a chemical protective overgarment in a 38°C, 30% RH environment when lower body exercise (treadmill walking; 1.26 m·s^{-1}) was performed. They report that cooling a larger body surface area (torso, thigh and upper arm cooling compared to torso cooling) lowered increases in T_C and sweat rate. They also found that cooling a larger skin surface area at a lower temperature (20° compared to 26°C) reduced HR responses (≈ 8 bt·min^{-1} overall) during exercise. Participant's also perceived higher thermal sensation values when 26°C liquid was used to cool skin surfaces compared to when 20°C liquid was used, validating the use of this groups thermal sensation scale (0-8 with appropriate verbal anchors ranging from unbearably cold to unbearably hot).

When the benefits of a liquid-cooled system were compared against an air-cooled system in an EOD suit the former caused larger final T_C (37.81±0.04°C compared to 38.42±0.18°C), HR (112.0±4.0 bt·min^{-1} compared to 156.6±8.2 bt·min^{-1}) and fluid loss (0.79±0.16 kg compared to 1.57±0.29 kg) reductions during 90 min of related activities at 34°C, 80% RH (Frim and Morris 1991). They observed that this system reduced heat strain to an equivalent level to when the EOD suit was not worn. Again during EOD related activities Kistemaker, den Hartog and Koerhuis (2006) report that a liquid-cooled system limited T_C increases to 0.2°C compared to an increase of 0.35°C when a phase change material was worn in a 25°C environment.

These two studies suggest that circulating cooling fluid next to the skin surface is the most efficient method of reducing the microenvironment temperature. However to maximise its efficacy optimal fitting of the device is needed in regards to its placement and cooling control (Flouris and Cheung 2006). Also a lightweight high energy source needs to be developed (McLellan and Frim 1994) so it can cool participants for longer and not increase the mass and therefore the energy demands of moving in PPE. Kistemaker, den Hartog and Koerhuis (2006) also reported that the phase change material was preferred to the liquid cooled system by Dutch EOD personnel because it was more thermally comfortable where the liquid system was perceived as being too cold at the start of trials and impractical to use in the field.

Vallerand, Michas, Frim *et al.* (1991) however supports the use of an air-cooled system in reducing heat strain when PPE is worn as it caused larger percentage reductions in the rise of T_C (13%) and reduced sweat rate (13%) in unacclimated males in a 37°C, 50% RH environment compared to its liquid counterpart. The air-cooled system also obtained lower final HR and thermal comfort values compared to the liquid-cooled system. This was attributed to the configuration of the air-cooled system which flowed air directly over the entire skin surface of the torso allowing for larger amounts of heat dissipation.

A further system that has been reported to be of benefit is a dry-ice system (Thake and Price 2007). In combination with a lighter trouser configuration of an EOD suit this system reduced heat strain, shown via a lower T_C, compared to the levels experienced in the full suit with no cooling. However this particular system may be limited as its flow is not directed to multiply areas, only the wearers back which may prove to be intolerable to the wearer.

A more universally accepted method of increasing tolerance to heat is via an increase in aerobic capacity. A physical / aerobic training programme increases an individual's ability to dissipate metabolically generated heat. This occurs because physical training (10 days at 75% $\dot{V}O_{2peak}$ for one hour in 25°C) causes the initiation of vasodilatation and sweat thresholds to take place at a lower T_C (Roberts, Wenger, Stolwijk *et al.* 1977). Also increasing aerobic capacity facilitates an individual's ability to store heat in part through a reduction in resting T_C (Cheung and McLellan 1998a). Arterial blood pressure is maintained, causing less circulatory strain when heat is dissipated. In contrast using a near identical regime of 10 days cycle ergometry exercise (1 hour; 70-80% $\dot{V}O_{2peak}$) Nadel, Pandolf, Roberts *et al.* (1974) suggested that it was an enhanced peripheral sweat response that increased sweat rate (by 67%) and not a change in the 'zero point' of sweat initiation that enhanced the ability of the cardiovascular system to dissipate heat.

A decrease in T_C at rest, a slower rate of increase during exercise and an increase in the level tolerated at exhaustion are adaptations that occur and result in increased heat tolerance times when conducting physical / aerobic training protocols. These changes mediate the impact of a hot environment and protect the individual against possible hypohydration stress when exercise is performed in this type of environment (Cheung, McLellan and Tenaglia 2000). This will only improve heat tolerance if the rise in T_C, during training, is sufficient enough to stimulate the temperature regulating centre for heat dissipation (~1.1°C over 1 hour of cycle ergometry) as the degree and duration of these increases determines the extent of the adaptation (Avellini, Shapiro, Fortney *et al.* 1982).

However the benefits of a training intervention in improving physiological responses when PPE equipment is worn in the heat are questionable. Cheung and McLellan (1999b) report decreased T_{SK} and increased sweat rates when exercise (treadmill walking; 3.5 $km{\cdot}hr^{-1}$) took place in a NBC suit and in a hot ambient (40°C, 30% RH) environment following a short term aerobic training programme (12 days; 1 hour daily treadmill exercise in 22°C, 40% RH at 65% $\dot{V}O_{2peak}$). However no effect on T_C in the first 60 min of exercise or tolerance time was noted in response to the training programme in the hot environment but the rise in T_C and HR decreased in a thermoneutral environment. It can be summarised that long term improvements or high $\dot{V}O_{2peak}$ values provide the greatest heat protection (Cheung, McLellan and Tenaglia 2000). It is apparent that short term training programmes are not an adequate substitute (Cheung and McLellan 1999b) as they provide few of the benefits when trying to increase heat tolerance times when individuals wear PPE. One of these benefits is an increased ability to sweat, but this has little impact on levels of heat storage (Cheung, McLellan and Tenaglia 2000) in UHS conditions due to the physical restriction of evaporative heat loss. However if individuals were to complete a training programme wearing PPE it would increase the potential for them to also become heat acclimated due to the increased temperature and RH between the skin surface and the clothing layer.

2:5:1 Acclimation and its Effects on Heat Strain in Heat Whilst Wearing PPE

Heat acclimation is a period of artificial acclimatisation (Pandolf 1998) that aims to decrease physiological strain and the energy cost for a given task (Aoyagi, McLellan and Shephard 1997). Heat acclimation studies are common in athletic populations (Gill and Sleivert 2001; Sunderland, Morris and Nevill 2008) and they often follow a physical training programme. Physical training and heat acclimation affect both peripheral and central mechanisms (Nadel, Pandolf, Roberts *et al.* 1974) to decrease physical strain and therefore promote the ability to exercise in the heat (Armstrong and Maresh 1991). Aoyagi, McLellan and Shephard (1997) reported that wearing PPE in UHS conditions during heat acclimation stimulated few of the benefits of improving heat tolerance time, due to the discomfort associated with increased sweat accumulation (Aoyagi, McLellan and Shephard 1998; Table 1.), when high intensity exercise was completed.

Table 1. Examples of acclimation studies that have incorporated PPE into procedures (either during experimental trials of acclimation sessions or both) and the impact on physiological and psychological variables. All NBC clothing ensembles include combat clothing, NBC overgarment, rubber gloves rubber boots, respirator and a charcoal-filtered undergarment (that allows some sweat evaporation via limited mass penetration of air through the fabric). ↑ = increased, ↓ = decreased, T_C = Core temperature, T_{SK} = Skin temperature, TT = Heat tolerance time, SR = Sweat rate, SP = Sweat production, SA = Sweat accumulation in PPE, SE = Sweat evaporation. * = $P<0.05$, MF = Moderately fit, HF = Highly fit.

Author	Participants	Acclimation/Habituation	PPE Type	Physiological Responses in PPE	Psychological Responses in PPE
Aoyagi, McLellan and Shephard (1994)	Military personnel and university students (n=9)	6 days, 40°C, 30% RH, 60 min treadmill walking (45-55% $\dot{V}O_{2peak}$), water *ad libitum*, jogging shorts and T-shirt worn.	NBC clothing, (8.2 kg mass)	↓$\dot{V}E/\dot{V}O_2$, ↓T_C, ↓T_{SK} , slower HR↑, ↑SP & SA	No subjective changes
Aoyagi, McLellan and Shephard (1995)	Male military personnel and university students (n=16)	12 or 6 days. 40°C, 30% RH. 1 hour treadmill walking (1.34 $m{\cdot}s^{-1}$, 3-12% gradient), jogging shorts and T-shirt worn, water *ad libitum*.	NBC overgarment (8.7 kg mass)	6 days =↓T_C, ↓HR, ↑SA, ↑TT* 12 days = ↓$\dot{V}E$, ↓T_C, ↓T_{SK}, T_C-T_{SK} gradient widened, ↓HR, ↑SA, ↑TT*	↓Overall RPE* and thermal discomfort ratings (larger change after 12 days)
Cheung and McLellan (1998a)	Military personnel and university students (n=15) (some participants already familiar with NBC clothing)	2 x 5 days (separated by 2 days) (40°C, 30% RH) 60 min treadmill walking (4.8 $km{\cdot}hr^{-1}$, 3-7% gradient) NBC clothing worn.	Canadian forces NBC clothing (6 kg)	↓T_C* in HF, ↓T_C in MF, ↓T_{SK} in HF, ↓HR*, ↑SR*	No perceptual or cognitive variables measured

Table 1. Continued

Author	Participants	Acclimation/Habituation	PPE Type	Physiological Responses in PPE	Psychological Responses in PPE
McLellan and Aoyagi (1996)	Non-acclimated males (n=22)	12, 1 hour treadmill walking sessions in 40°C, 30% RH, NBC worn, T_C maintained by exercise intensity at 1.3°C above baseline measurement.	NBC clothing	↓HR, ↓T_{SK}, ↓T_C*, ↑SR*, ↑SE*, ↑TT.	No perceptual or cognitive variables measured
Millard, Spilsbury and Withey (1994)	Males (n=7)	5 or 10 days (WBGT=38°-40°C), treadmill walking (4.8 km·hr^{-1}) until T_C reached 38.8°C. Participants then sat (60 min), T_C maintained by intermittent walking ('light clothing' worn)	British Army chemical protective clothing	10 days= ↓T_C (initial/rate of rise and level at withdrawal), ↓initial T_{SK}, ↓HR throughout exposure, ↑fluid loss, ↑TT,	No perceptual or cognitive variables measured
Radakovic, Maric, Surbatovic *et al.* (2007)	Male Soldiers (n=40)	10 days passive (3 hours) or active (60 min treadmill walking at 5.5 km·hr^{-1}) 35°C, 40% RH in sports clothing.	Normal combat uniform (not fully encapsulating) with 20 kg backpack	↓ T_C, ↓T_{SK}	No change in rapid visual information processing or reaction time in response to acclimation protocol.
Shvartz, Saar, Meyerstein *et al.* (1973)	Males (n=9)	6 days, 37°C, (bench stepping; 15 times per min; 27.5 cm high) in a vapour barrier suit.	Vapour Barrier Suit (covered entire body except face, 4 kg mass)	↓HR, ↓T_C, ↓T_{SK}, ↓%$\dot{V}O_2$, ↑SR, ↑TT	No perceptual or cognitive variables measured

In fact physiological tolerance is similar when moderate (425 W) and high (600 W) intensity treadmill exercise is performed in both a tropical (35°C) and desert (43°C) climate that have the same wet bulb globe temperature (WBGT) when participants are fully encapsulated (Montain, Sawka, Cadarette *et al.* 1994). To reduce heat strain, and avoid heat illness, intermittent exercise should be incorporated if PPE is worn (McLellan and Aoyagi 1996; Millard, Spilsbury and Withey 1994). However in most cases sports or basic military clothing is worn when participants complete heat acclimation sessions (Aoyagi, McLellan and Shephard 1998). McLellan and Aoyagi (1996; Table 1.) report that significant changes occur to the individual in PPE as a result of wearing it during heat acclimation sessions, allowing for individual's to become habituated which decreases the relative intensity of given tasks in heat.

Another factor to consider when undertaking heat acclimation is the type of environment used. The time course is similar between wet and dry-heat acclimation if they have the equivalent thermal properties in terms of WBGT (Griefahn 1997). However they induce different adaptations, dry-heat does not improve heat tolerance when PPE is worn in the heat (McLellan and Frim 1994). But wearing NBC clothing during acclimation sessions, to create a wet-heat microenvironment will decrease T_{SK} and the rate of increase of T_C as well as increase tolerance time when the NBC garment is worn during heat-stress tests (McLellan and Aoyagi 1996).

To induce and maintain the benefits of heat acclimation repeated daily exposure to heat is required. Larger decreases in HR, final T_C and T_{SK} were seen in 14 competitive rowers when a consecutive 10 day heat acclimation period was compared to an intermittent period (ten sessions over three weeks). However each heat exposure entailed participants exercising for 30 min at 70% $\dot{V}O_{2peak}$ in 38°C, 70% RH while wearing sports clothing (Gill and Sleivert 2001). The number of exposure sessions needed to gain the benefits of heat acclimation alters with physical fitness. Individuals with a $\dot{V}O_{2peak}$ of 65 ml·kg·min^{-1} required only four days of heat exposure to acquire 75% of all physiological adjustments (Pandolf 1998) to occur where individuals with a $\dot{V}O_{2peak}$ of between 40 and 50 ml·kg·min^{-1} required six to eight exposure days demonstrating why a physical training programme often precedes heat acclimation (Pandolf, Burse and Goldman 1977).

Physical fitness seems to be the determining factor in the rate of heat acclimation. Aoyagi, McLellan and Shephard (1994; Table 1.) report that a 6-day heat acclimation period (40°C, 30% RH at 45-55% $\dot{V}O_{2peak}$ for 60 min) induced reductions in T_C and T_{SK} after 40 min of exercise (4.8 km·hr^{-1}, 2% gradient) in the heat (40°C, 30 %RH) when endurance trained participants wore NBC suits. When untrained participations ($\dot{V}O_{2peak}$; 42 ml·kg·min^{-1}) completed the same protocol only final T_C was reduced (0.2-0.4°C). Extending the acclimation protocol to 12 days (treadmill walking; 50% $\dot{V}O_{2peak}$, 40°C, 30 RH) did not further improve heat tolerance times in the NBC suit. Tolerance was extended by 12 min after the 12-day protocol and by 15 min following the 6-day protocol, this is possibly due to the extended training period fatiguing participants (Aoyagi, McLellan and Shephard 1995; Table 1.). The 12-day protocol did however reduce $\dot{V}E$ when NBC clothing was worn by a larger magnitude (from 21.2±1.3 to 19.0±1.0 L·min^{-1}) than the reduction seen after 6 day acclimation (from 21.6±1.0 to 21.3±21.3 L·min^{-1}). Even so no $\dot{V}O_2$ differences were observed following either 6 or 12 acclimation sessions possibly due to PPE not being worn during them. If it had have been the relative work intensity (%$\dot{V}O_{2peak}$) may have been reduced and movement economy increased as participants could have become habituated to the physical demands of the clothing. For example when vapour barrier clothing, that weighed 4 kg in mass and covered the entire body except the face, was worn during acclimation sessions (90 min, or until volitional exhaustion; bench stepping, 15 steps per min, 27.5 cm high) in a 37°C, 20% RH environment partial adaptations such as a lower resting T_C (0.3°C), and T_{SK} (0.5°C) were observed between data sets gathered during acclimation sessions 6 compared to session1. HR was lower (16 bt·min^{-1}) at the corresponding exhaustion time (recorded from session 1) and %$\dot{V}O_{2peak}$ (13%) declined during exercise, also sweat rate (25%) and tolerance time (13 min) increased (Shvartz, Saar, Meyerstein *et al.* 1973; Table 1.).

Once heat acclimation is achieved its decay is relatively slow. Initial loss in a relatively fit population is small with a decline following acclimation of 18% for T_C and 20% for HR after 12 days (Pandolf, Burse and Goldman 1977). However measuring the decline in heat acclimation is difficult as the present literature analyses inappropriate measures and assesses it when complete heat acclimation has not been achieved. Pandolf, Burse and Goldman (1977) also indicated that a high $\dot{V}O_{2peak}$ is the prime factor in rapid reacclimation. 24 relatively fit (49.5±1.2 ml·kg·min^{-1}) soldiers became reacclimated following 12 days of no heat stimulus after two days of exposure to 110 min treadmill walking (1.34 $m{\cdot}s^{-1}$) in 49°C, 20% RH, 1.4 $m.s^{-1}$ wind speed while wearing sports clothing. However Pivarnik and Senay (1986) state that a single exercise bout (90 min stationary cycling, 60% $\dot{V}O_{2peak}$, 20°C) and / or heat exposure (40°C, 30-35% RH) per week is insufficient in maintaining increased vascular volumes and heat acclimation.

According to Senay, Mitchell and Wyndham (1976) the most critical event of heat acclimation is an increase in plasma volume, caused by the transfer of interstitial proteins and water into the vascular volume. After two days of four hour exercise at 40-50% $\dot{V}O_{2peak}$ (25°, dry-bulb and 18°C; wet-bulb) a 9% increase was observed. Plasma volume increases are dependent on fitness, an individual with a high $\dot{V}O_{2peak}$ is likely not to experience these increases (Aoyagi, McLellan and Shephard 1997) even if other factors, such as T_C are affected as they will already have a fitness induced increased blood volume (Houmard, Costill, Davis *et al.* 1990).

Increases in intravascular volume augment the capacity to create a dilute (decreased sodium content) sweat (Cheung, McLellan and Tenaglia 2000). When PPE is worn there is an increase in sweat production (and accumulation) at rest and at a given work rate as long as the exposure causes a sufficient increase in T_C (Aoyagi, McLellan and Shephard 1997). When normal clothing was worn following the same protocol (treadmill walking; 1.34 $m{\cdot}s^{-1}$, 2% gradient; 40°C, 3% RH; until exhaustion) no changes in sweat values were seen (Aoyagi, McLellan and Shephard 1998). This indicated that heat acclimation increased sweat production but PPE limited its evaporation away from the skin surface. The final way that heat acclimation alters sweat response is that it shifts skin surface vasodilatation initiation to a lower T_C (0.26±0.06°C) value (Roberts, Wenger, Stolwijk *et al.* 1997).

The affects of heat acclimation are dependent on the change of this vasodilatation threshold to decrease inactive muscle and viscera blood flow at a given work rate (Aoyagi, McLellan and Shephard 1997) to augment skin blood flow, aid metabolic heat dissipation and reduce the onset of heat storage. Following a 10-day heat acclimation programme involving intermittent cycle ergometer exercise (50% $\dot{V}O_{2peak}$) in 35°C a lower T_C value (0.26±0.06°C) was observed for the initiation of forearm blood flow (Roberts, Wenger, Stolwijk *et al.* 1977). However this adaptation was acquired when sweat evaporation was not restricted, if PPE had have been worn these changes could have increased further as T_{SK} increases when participants are fully encapsulated.

The affect of heat acclimation on reducing perceptual strain when PPE is worn is an area of little research. Of that that has been conducted no changes in thermal discomfort and perceived exertion have been noted (Aoyagi, McLellan and Shephard 1998) and thus no change in PeSI and PhSI as noted by their relationship (Section 2:3:1). This could be due to the clothing ensemble not been worn during heat acclimation sessions, if it was participants may have become habituated to the demands and discomforts of the microenvironment (McLellan 2001). Taylor and Orlansky (1993) reiterate this and state that training in the clothing that participants are to wear facilitates learning and reduces negative effects on concentration performance. This research was conducted in a temperate environment so whether results in the heat and PPE would follow this pattern also need to be addressed.

As already stated cognition in the heat is improved through acclimation however the heat has only been shown to affect complex tasks (perceptual motor and dual tasks). Nevertheless Radakovic, Maric, Surbatovic *et al*. 2007 (Table 1.) report that both a 10 day passive and / or active (1 hr treadmill walking; 5.5 $km \cdot hr^{-1}$) acclimation programme prevented a reduction in attention performance in 40°C environment. This is possibly due to the clothing ensemble that participants wore during heat-stress tests, even though they carried a 20 kg backpack the clothing did not severely restrict heat loss pathways. If they had have worn a piece of PPE that did impede heat loss cognition may have been severely restricted with a reduced effect if it was worn during heat acclimation sessions.

2:7 Rationale for Current Research

To the authors knowledge no work has been conducted to examine the impact of repeated activity bouts whilst wearing an EOD suit in a moderate ambient temperature (20°C) on the subsequent performance of physiological responses to a bomb disposal related activity in moderate (20°C) and hot (40°C) conditions. Furthermore, operationally it may be of use to establish whether the benefits, if there are any, from wearing the EOD suit can be transferred to a hot environment. To do this the suits internal fan system would need to be turned off during acclimation sessions to create a UHS microenvironment to stimulate acclimation. This research may also provide information on the capabilities of operatives that are moving from a temperate to a hot environment and assess any benefits of acclimation to operatives in both a temperate and hot climate.

Many methods of evaluating physiological strain have been suggested (heat stress index; HSI and cumulative heat strain index; CHSI) and the majority of them would have no use in becoming a universal scale of strain (Moran, Shitzer and Pandolf 1998). This is because they only depict physiological strain accurately when certain clothing ensembles are worn in specific environments when particular exercise procedures are completed due to the number of variables that they measure and incorporate into physiological strain equations. The one exception to this trend seems to be the PSI (Moran, Shitzer and Pandolf 1998; Section 2:3:1) which was able to distinguish differences in strain between several different clothing, environment and exercise intensity situations. This index is also capable of being applied in real time to provide constant information of the physical state of the operative however it has not yet been applied to a simulated protocol. The only issues that arise with the PSI are the restrictions that are placed on the increases and baseline values of the two physiological variables (T_C and HR). As noted in Section 2:3:1 PhSI (Tikuisis, McLellan and Selkirk 2002) removes HR restrictions and so could potentially be a more valid measure of physiological strain.

Therefore the aim of this study is to evaluate the effect of six, one hour acclimation / habituation sessions whilst wearing an EOD suit at 20°C ambient temperature on physiological and perceptual responses to an EOD related activity sequence in moderate (20°C) and hot (40°C) conditions.

3 METHODS

3:1 Overview

Prior to acclimation / habituation sessions participants visited the laboratory on five different occasions. On the first visit they undertook a familiarisation session and on the other four they completed experimental trials either wearing or not wearing the EOD suit in both 20° and 40°C. Once six acclimation / habituation sessions were finished participants then carried out the same four experimental trials that were completed before acclimation / habituation (Figure 1.).

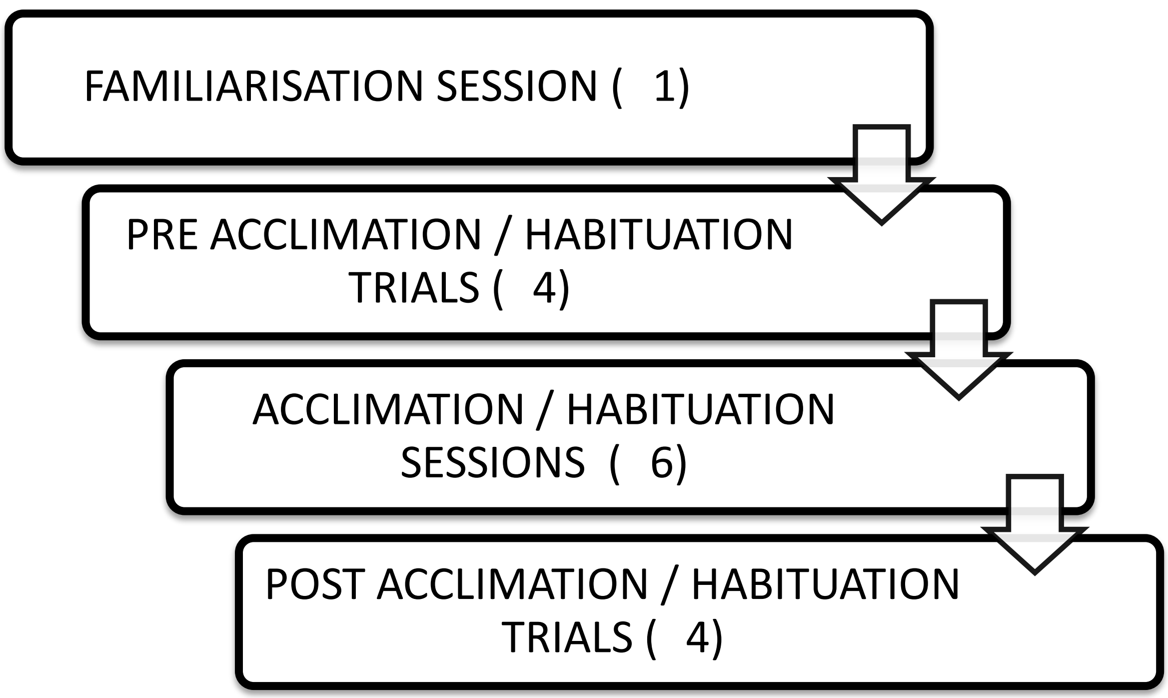

Figure 1. Overview of Study Design.

Only one trial / session was completed on any one day. The format of the study also incorporated rest days to facilitate recovery and eliminate participants becoming fatigued (Appendix B). Experimental trials followed a one day on one day off design for eight days. Acclimation / habituation sessions followed a two days on one day off procedure for nine days. Therefore participants were involved in the study for a total of twenty-four days.

The following clothing ensembles were used in this investigation;

1. No Suit; Military clothing (Figure 2.) – consisted of underwear, socks, standard combat trousers and T-shirt and leather steel toed boots with a total mass of ≈ 2.6 kg (varied depending on sizes). Once all scientific instrumentation equipment was added the total mass worn by participants increased by 2.6 kg to ≈ 5.2 kg.

2. MK VI Explosives Ordnance Disposal suit (Figure 3.) – consisted of wearing military clothing (as outlined above) beneath the protective clothing ensemble that consisted of a helmet; jacket with a fan cooling system; front shield; and trousers. The total mass being 35.8 kg. Again once all scientific instrumentation equipment was added the total mass of the ensemble increased by 2.6kg to ≈ 38.4 kg.

Figure 2. Military clothing ensemble (scientific equipment also worn).

Figure 3. EOD ensemble with modified helmet (scientific equipment also worn).

3:2 Participants

With ethical approval from Coventry University ethics committee five male and one female (Table 2.) healthy and injury free, as defined by health screen questionnaires, individuals participated in the investigation. All were non smokers and had no known history of any cardiorespiratory disease.

Table 2.The physical characteristics of participants (n=6).

Participant	Sex	Age (yrs)	Body Mass (kg)	Stature (cm)	Body Mass Index (BMI)
1	Male	20	94.8	185.8	27.5
2	Male	20	88.2	177.0	28.2
3	Male	22	74.2	173.2	24.7
4	Male	25	70.1	169.9	24.3
5	Female	25	63.4	175.2	20.7
6	Male	19	86.4	176.6	27.7
MEAN±SD	**-**	22±3	79.5±12.1	176.2±5.3	25.5±2.9

3:3 Familiarisation Session

Prior to involvement in any experimental trials participants visited the laboratory for a familiarisation session, during which informed consent and health screen questionnaires were completed prior to donning the EOD suit. Within this visit the experimental protocol was explained and at an ambient temperature (≈ 20 °C) participants wore the military clothing ensemble while they performed one 16:30 (min:sec) cycle of the simulated EOD activity sequence (Figure 6.).

3:4 Donning the Suit:

The preparation of participants for experimental trials followed the same procedure on each occasion;

1. At an ambient temperature of ≈ 20°C nude body mass was measured (see *Mean Sweat Rate Measurement*). Then core and skin surface thermistors (Figure 8.) were fixed to the participant (see *Temperature Measurements*).

2. Participants were dressed in the military clothing (Figure 2.) and the face mask of the breath by breath analysis device (Cosmed K4b^2; Cosmed Pulmonary Function Equipment; Rome, Italy) was fitted.
    a. The first T_C, T_{SK} and HR baseline measurements (B1; Figure 6.) were recorded immediately.
    b. If the trial being completed did not require the participant to wear the EOD suit (Figure 3.), the Cosmed K4b^2 device was placed over their shoulders (see *Heart Rate and Metabolic Measurements*) and they then entered the environmental chamber to commence the trial.
3. In EOD trials participants were now then dressed in the EOD suit. The trousers were placed on first, followed by the jacket, the shield, the Cosmed K4b^2 unit (see *Heart Rate and Metabolic Measurements*) and finally the helmet.
    a. The second set of T_C, T_{SK} and HR baseline measurements (B2; Figure 6.) was recorded.
    b. Participants now entered the environmental chamber and the trial commenced within the first minute of entry.

A timescale of 9:30 (min:sec) from when the first item of the EOD suit was placed on a participant to the time that they entered the environmental chamber was kept constant.

3:5 Experimental Trial Design

The study ran between February and May (this limited initial heat acclimation caused through casual exposure to high ambient temperatures). To offset any effects of the circadian rhythm participants completed all of their trials at the same time of day. Four experimental trials were completed before (PRE) and following (POST) the acclimation / habituation period. In the first and third trials participants wore military clothing (Figure 2.) and in the second and forth trials the EOD suit (Figure 3.) with the fan system engaged, was worn. The order of the clothing ensemble worn in each trial was fixed to alleviate the potential effect of fatigue and enable time for recovery of carrying the EOD suit load (alternatively EOD and NS trials) whereas temperature was applied in a cross over fashion. Therefore each set of four trials consisted of;

- 20°C wearing military clothing (20 NS)
- 20°C wearing the EOD suit (20 EOD)
- 40°C wearing military clothing (40 NS)
- 40°C wearing the EOD suit (40 EOD)

Ambient temperatures (°C) and relative humidity (%RH) were recorded (Testo 175 compact data logger, Testo. AG; Lenzkirch, Germany) in the environmental chamber during experimental trials (Table 3; Figure 4; Figure 5). Table 3. presents the mean (±SD) ambient temperature and RH recorded for each trial (Figure 6.) and Figure 4. and Figure 5. show the mean (±SD) of all values recorded at each exercise stage of the EOD related activity sequence in both 20° and 40°C trials. This information shows that RH is consistently ≈ 15% lower in 40° trials compared to 20°C allowing for a greater capacity of evaporative heat transfer.

Table 3. Ambient temperature (°C) and relative humidity (%) (mean±SD) recorded from all stages of EOD related activity sequence during each PRE and POST acclimation / habituation trial.

Trial	Temperature (°C)	Relative Humidity (%)
20 NS PRE	21.4±1.0	44.2±5.8
20 NS POST	21.2±0.9	47.1±5.9
20 EOD PRE	22.4±1.3	45.6±5.4
20 EOD POST	21.8±1.2	46.0±5.4
40 NS PRE	40.0±1.0	30.0±6.7
40 NS POST	40.1±0.4	30.5±6.7
40 EOD PRE	40.0±0.7	28.2±5.8
40 EOD POST	40.4±0.6	29.5±6.8

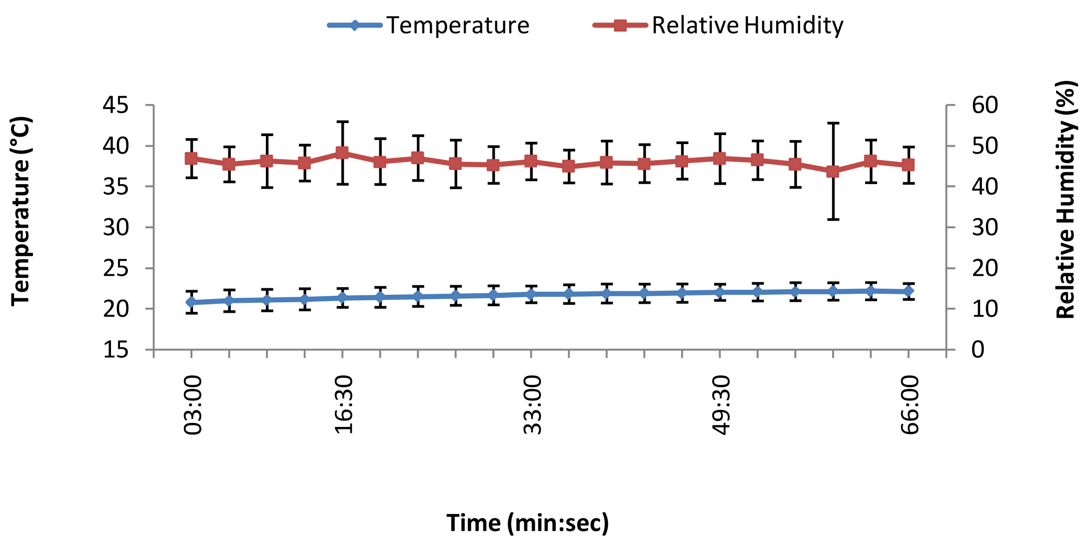

Figure 4. Ambient temperature (°C) and relative humidity (%) recorded during all 20°C (PRE and POST acclimation / habituation) trials. Values are mean±SD.

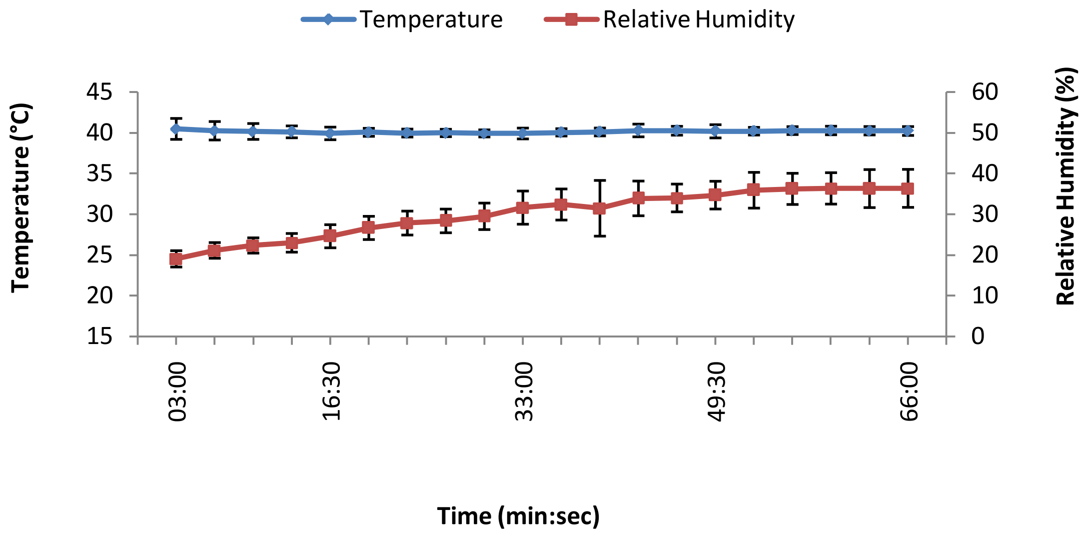

Figure 5. Ambient temperature (°C) and relative humidity (%) recorded during all 40°C (PRE and POST acclimation / habituation) trials. Values are mean±SD.

During each experimental trial participants were requested to complete a sixty-six minute (4 × 16:30 min:sec cycles) intermittent exercise protocol (Figure 6.). The EOD related activity sequence was designed to replicate the physical tasks that operatives encounter in the field (Thake and Price (2007). Each cycle represents an operative walking 200 m towards a potential threat (treadmill walking), then handling their tools in preparation for their use (manual loading). The crawling and searching activity represents the operative searching for the potential threat and positioning themselves so that they can work effectively. Unloaded arm ergometry exercise is a representation of the operative using their tools to diffuse the potential threat. Finally the rest period is incorporated into the sequence so that the participant can recover from the exercise undertaken and their physical state can be assessed.

The treadmill walking (4 km·hr^{-1}), unloaded arm ergometry (60 rpm) and rest stages were not altered as the protocol already had a fixed workloads which eliminated any variability between trials. Key changes from the Thake and Price (2007) protocol were made in the manual loading and crawling and searching activities. They were standardised so that all participants completed the same amount of work, enabling the comparison of physiological changes, between trials as opposed to differences in performance. Manual loading consisted of participants kneeling and moving four 1.25 kg weights between two shelves one shelf was 64 cm from the floor the other was below this, 27 cm from the floor. Weights were moved on the beat of a metronome (Seiko DM-20, Hattori Seiko Co. Ltd; Japan) that was set at thirty beats per minute. In the crawling and searching activity a 2.25 m ‘ladder’ design was marked on the environmental chamber floor (Figure 7.). Participants were then asked to move their hands (24 cm) to the next bar on the ladder in time with the metronome which was again set at 30 beats per minute. At either end of the ladder they ‘searched’ by moving their head to their left and right twice on the beat of the metronome. They then crawled backwards along the ‘ladder’ with each hand moving 24 cm behind the other. Once they were at the end of ‘ladder’ they ‘searched’ again (Figure 7.). This procedure was completed twice during each of the four activity cycles (Figure 6.).

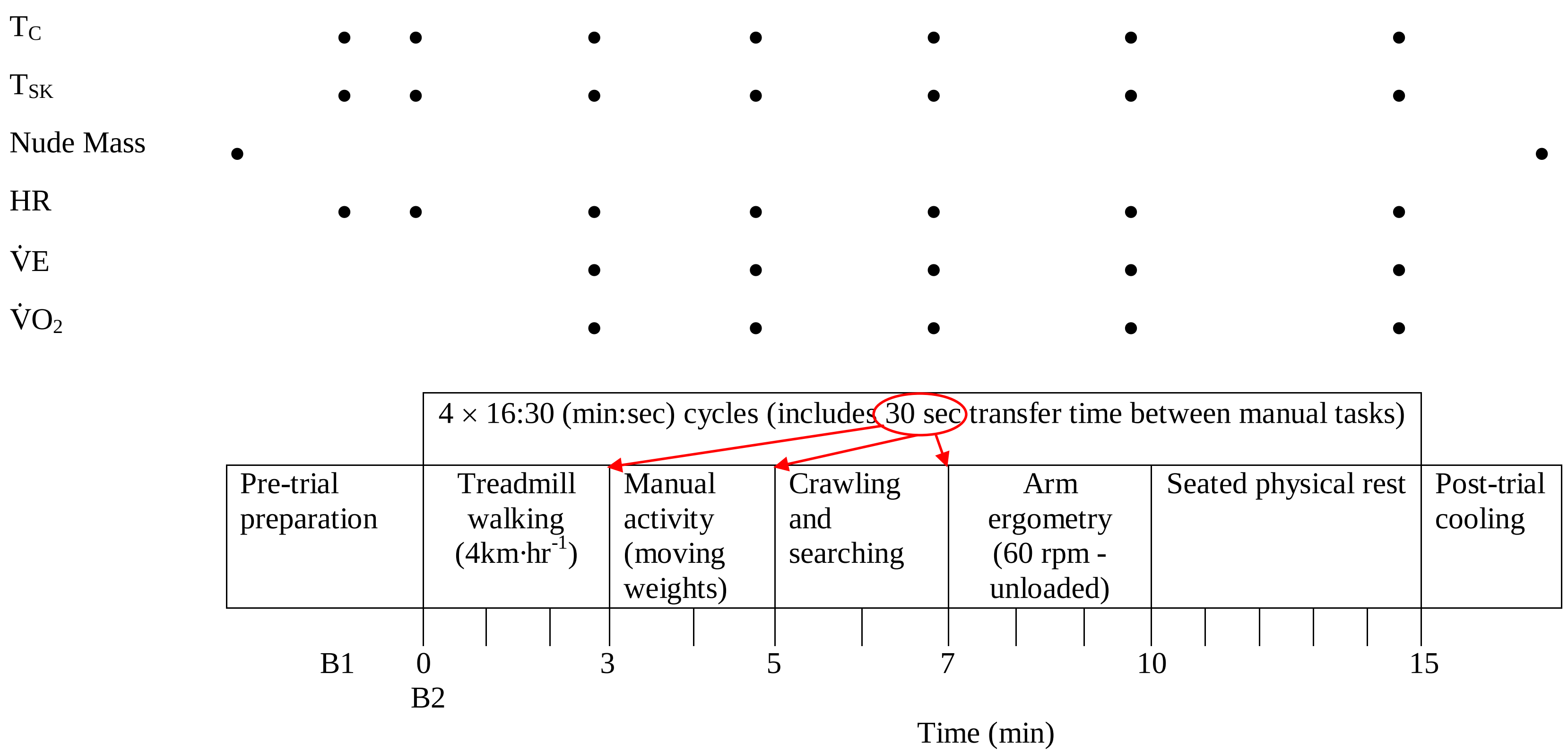

Figure 6. EOD activity sequence (rest periods signified) conducted during all PRE and POST trials (Thake and Price 2007). A maximum of four cycles was completed during each trial. HR, T_C, T_{SK}, $\dot{V}O_2$ and $\dot{V}E$ monitored continually. Participants donned the basic military clothing ensemble prior to B1 and the EOD ensemble between B1 and B2. • denotes stage where data was recorded for subsequent analysis.

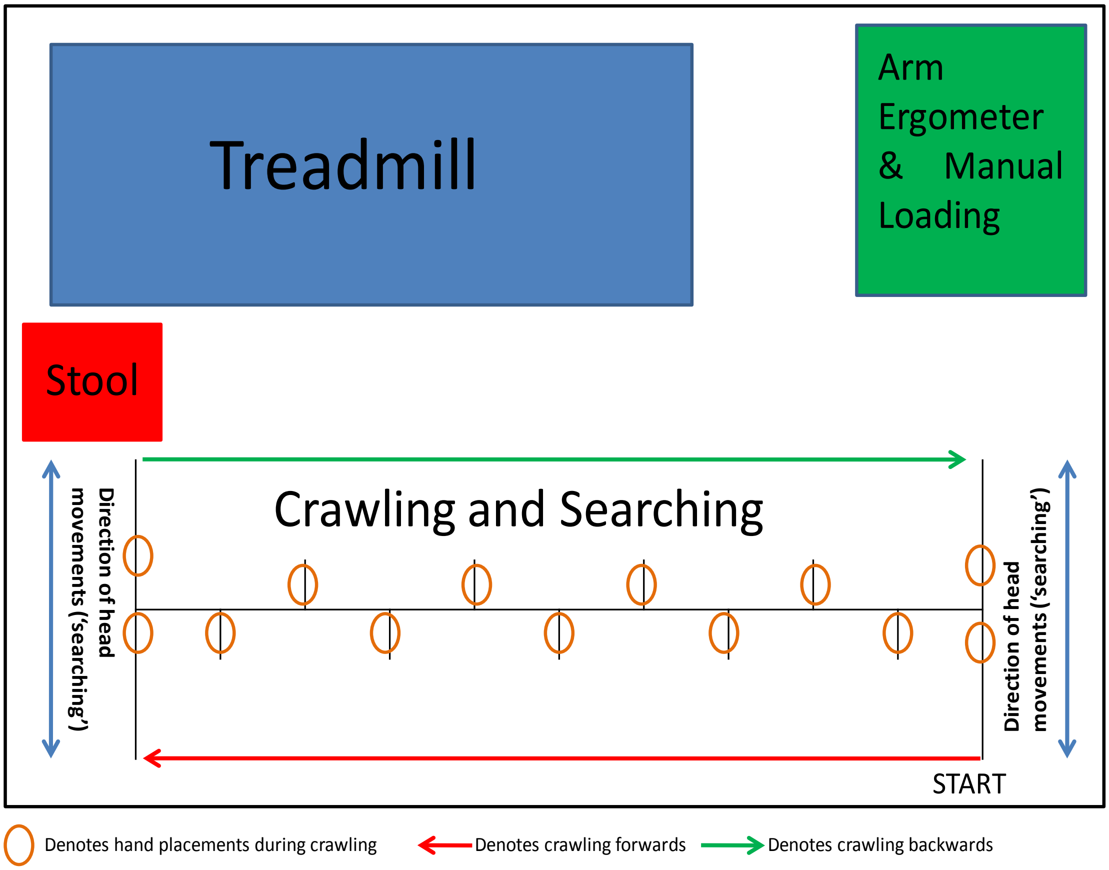

Figure 7. Environmental chamber floor (3 m × 5 m) plan (equipment not to scale).

3:5:1 Temperature Measurements:

A Squirrel SQ 2020 data logger (Grant Instruments; Cambridgeshire, UK) recorded core and skin temperatures at 15 second intervals. Core temperature (T_C) was detected using a flexible translucent PVC rectal probe (Grant Instruments; Cambridgeshire, UK) inserted approximately 10 cm above the anal sphincter. Skin temperature was detected at 4 sites on the left side of the body (lateral calf, medial thigh, upper arm and chest; Figure 8.) using stainless steel mounted thermistors (Grant Instruments; Cambridgeshire, UK). Baseline measurements were recorded prior to the beginning of exercise at each trial when participants were wearing just the military clothing ensemble (B1; Figure 6.). If the trial involved the participant wearing the EOD a second set of baseline measurements were recorded once the full suit was donned (B2; Figure 6.), between eight and nine minutes after the first item of clothing was placed on the participant. Mean skin (T_{SK}) temperature was calculated from individual skin site temperatures (Equation 1.). Heat storage ($J \cdot g^{-1}$) was then derived from increases in T_{SK} and T_C (Equation 2.).

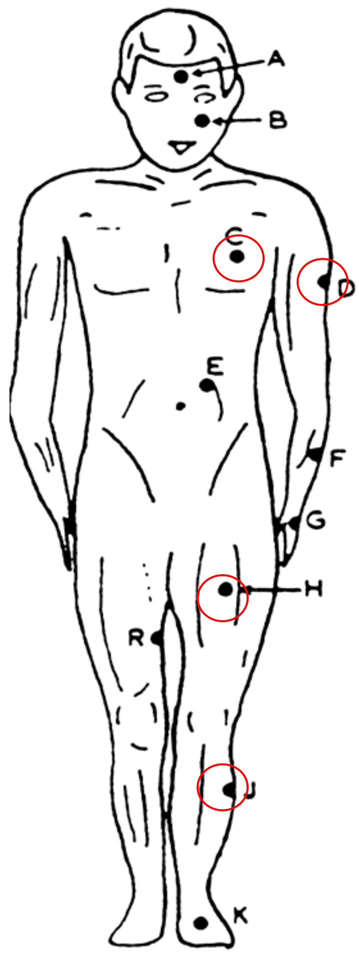

Figure 8. Skin sites (circled) where skin thermistors were fixed to measure individual skin temperatures. From which T_{SK} was calculated.

Equation 1: Mean Skin Temperature = 0.30(Chest + Arm) + 0.20(Thigh + Calf)

(Ramanathan 1964)

Equation 2: Heat Storage ($J.g^{-1}$) = $[(0.8 \times \Delta T_C) + (0.2 \times \Delta T_{SK})] \times CB$

(Havenith, Luttikholt and Vrijkotte 1995)

3:5:2 Heart Rate and Metabolic Rate Measurements:

Heart Rate ($bt \cdot min^{-1}$; Polar Accurex Plus, Polar electro Oy; Kempele, Finland) was logged telemetrically in real time via Cosmed K4b^2 software. The EOD helmet was adapted to accommodate the face mask of the Cosmed K4b^2 breath by breath analysis system. This system displayed and recorded oxygen consumption ($\dot{V}O_2$; $L \cdot min^{-1}$; Standard Temperature Pressure Dry, STPD) and minute ventilation ($\dot{V}E$; $L \cdot min^{-1}$; STPD) on a real time basis. This real time data also served as a constant assessment of a participant's physical state and contributed to evaluating their wellbeing. The system was calibrated before each trial using an ambient air sample, where oxygen content was assumed to be 20.93% and carbon dioxide was assumed to be 0.03%. In addition the system was also calibrated using a gas sample with known gas fractions (O_2; 15%, CO_2; 5%) and the turbine was calibrated using 3000 ml calibration syringe. The phase delay (msec), to take into account the lag phase due to the length of the sampling line, was calibrated in accordance with the manufacturers guidelines.

3:5:3 Calculation of Physiological Strain:

Physiological strain was calculated from T_C and HR data using two equations the PSI (Equation 3; Moran, Shitzer and Pandolf 1998) and PhSI (Equation 4; Tikuisis, McLellan and Selkirk 2002). Both normalised increases in HR and T_C with equal weight and described physiological strain on a 0 (no strain) to 10 (very high strain) scale.

Equation 3: $PSI = 5[(T_{Ct} - T_{C0}) \div (39.5 - T_{C0})] + 5[(HR_t - HR_0) \div (180 - HR_0)]$

$_t$ denotes value at a given time point. $_0$ denotes baseline value.

Equation 4: $PhSI = 5[(T_{Ct} - T_{C0}) \div (39.5 - T_{C0})] + 5[(HR_t - 60) \div (HR_{max} - 60)]$

$_t$ denotes value at a given time point. $_0$ denotes baseline value. $_{MAX}$ denotes maximum HR value seen from all trials.

<u>3:5:4 Calculation of Mean Sweat Rate::</u>

Mean sweat rate was calculated from the difference in nude body mass (Seca 770 digital scales, Vogel & Halke; Hamburg, Germany) measured pre and post each trial (Equation 5.).

Equation 5: Mean Sweat Rate ($L \cdot hr^{-1}$) = (Change in Mass ÷ Trial Duration) × 60

<u>3:5:5 Perceptual Measurements:</u>

Participants rated overall and local body segment perceived exertion (RPE; Borg 1970) on a 15 point scale (6 – 20), perceived thermal sensation on a (Young, Sawka and Epstein *et al*. 1987) on a 9 point scale (0 – 8) and perceived thermal comfort (Epstein and Moran 2006) again on a 9 point scale (0 – 8) in a fixed order. Refer to Appendix C for scales and their verbal anchors. Participants separately rated their local body segment

RPE for their upper back and shoulders, lower back and legs during the treadmill and arm ergometry stages of the sequence. Levels of local thermal sensation and local thermal comfort were rated for the participants back, chest and arms, groin and legs. These values were recorded during the arm ergometry and rest stages of the activity sequence (Table 4.). RPE, thermal sensation and thermal comfort were also initially recorded at B1, B2 (Table 4.). Additionally during the activity sequence rest stage subjects also were asked a series of questions regarding their wellbeing using a General Symptoms Questionnaire (GSQ) scoring system (Thake 2006; Appendix C). This scoring system enabled participants to relay information regarding the severity of the following symptoms; headache, sickness, light-headedness, mental confusion, tiredness and difficulty breathing experienced within each trial (Table 4.).

Table 4. Protocol stages where overall and local body segment RPE, thermal sensation, thermal comfort and GSQ scores were recorded. • denotes stage where variable was taken during all PRE and POST acclimation / habituation trials.

	Baseline 1	**Baseline 2**	**Treadmill**	**Manual Activity**	**Searching & Crawling**	**Arm Ergometry**	**Seated Rest**
RPE			●			●	
Thermal Sensation	●	●				●	●
Thermal Comfort	●	●				●	●
GSQ							●

3:5:6 Calculation of Perceptual Strain:

RPE and thermal sensation values acquired from the arm ergometry stage of each cycle (Figure 6.) were adapted from the 15 and 9 point scales to an 11 (0–10) and a 7 (7–

13) point scale so that a perception based strain index (PeSI) could be calculated (Equation 6; Tikuisis, McLellan and Selkirk 2002). This equation normalised increases in RPE and thermal sensation with equal weight and described perception based strain on a 0 (no strain) to 10 (very high strain) point scale.

Equation 6; $PeSI = 5[(TS_t - 7) \div 6] + 5[RPE_t \div 10]$

$_t$ denotes value at a given time point.

3:5:7 Trial Termination Criteria:

Exercise continued until the completion of the 66 min trial or until the subjects T_C exceeded 39.5°C or increased in excess of 2°C above initial temperature. Other physiological criteria used to inform participation cessation were a HR in excess of $95\%_{MAX}$ (determined as 220 – age) > 3 min. Perceptual criteria used to inform trial termination were an RPE of 20 or a thermal sensation of 8. Participants could also inform the investigator that they would like to terminate trials if they felt unwell or maximally fatigued. In addition, if the participant reported significant symptoms related to heat stress (GSQ) with a total score ≥ 6 the trial would cease.

3:6 Acclimation / Habituation Session Data

Six acclimation / habituation sessions were conducted over nine days as three consecutive cycles of two days acclimation / habituation sessions followed by a rest day (Appendix B). The full EOD ensemble without its fan system turned on was worn and participants walked on a treadmill (4 km·hr^{-1}) for 60 min in an ambient environment of 21.6±1.2°C, 47.0±5.4% RH (Figure 9.). If they were unable to complete this protocol they exercised until volitional exhaustion occurred and spent the remainder of the 60 min seated at rest, still wearing the full EOD suit without its fan system turned on.

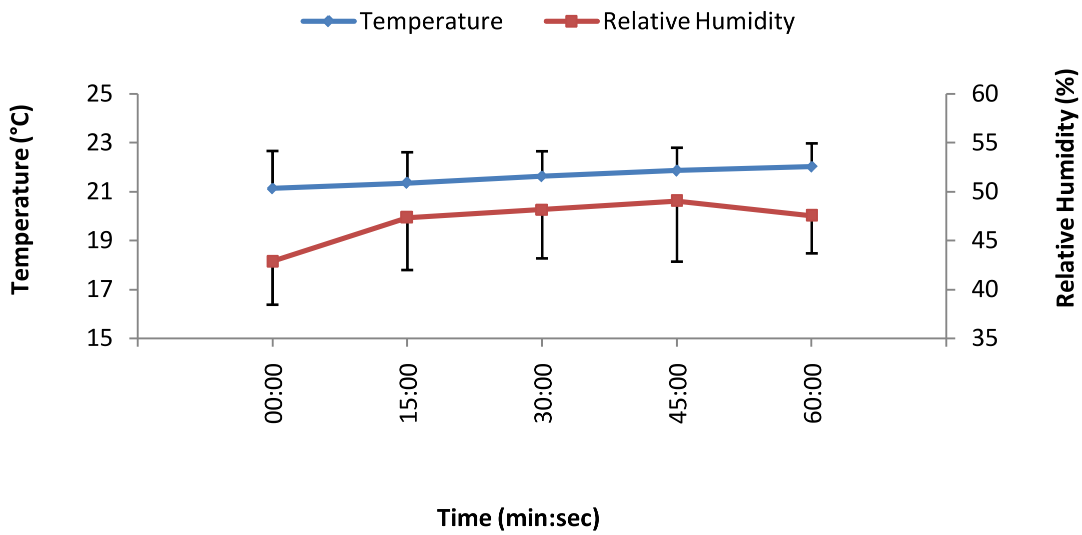

Figure 9. Ambient temperature (°C) and relative humidity (%) recorded every fifteen minutes during all acclimation / habituation sessions. Values are mean±SD.

3:6:1 Measurements:

Baseline variables were recorded twice, as with EOD experimental trials, firstly with participants dressed in the military clothing ensemble and then with the EOD suit on, 4:30 (min:sec) after the first item of the suit was placed on them. Nude body was measured prior to and following each acclimation / habituation session. Once exercise commenced HR and T_C, measured via a PVC coated aural thermistor (Grant Instruments; Cambridgeshire, UK) were manually recorded every 15 min of exercise. Overall and local body segment RPE, thermal sensation and thermal comfort were also requested in a fixed order at these time points. The first and sixth acclimation / habituation session data was compared using a general linear model ANOVA.

3:6:2 Acclimation / Habituation Session Results:

3:6:2:1 Aural Temperature:

Aural temperature (°C) recorded at 15 min intervals (Figure 10.) increased (P<0.001; main effect) over time during all acclimation / habituation sessions however the rate or magnitude of rise did not vary between the first and sixth acclimation / habituation sessions. However tolerance to the exercise stimulus did improve from three participants completing the exercise protocol in session 1 with mean tolerance time recorded of 50:30±12:04 (min:sec) compared to four participants completing the final session with mean tolerance time increasing to 54:00±10:54 (min:sec). Also the time for aural temperature to increase in excess of 1°C from baseline measurements increased from 23:12±13:22 (min:sec) in session 1 to 30:45±14:56 (min:sec) in session 6.

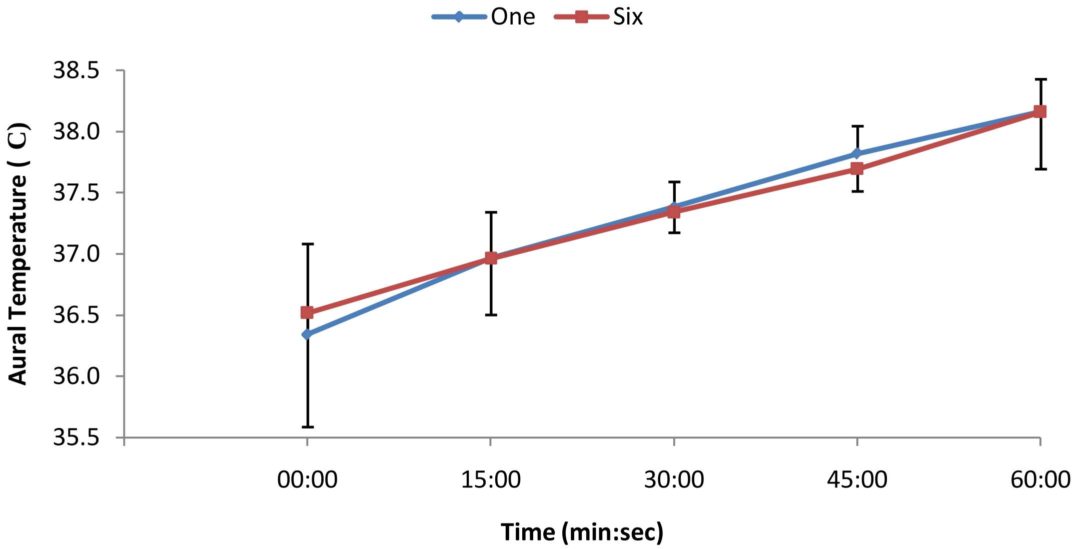

Figure 10. Aural Temperature (°C) responses over acclimation / habituation session one (first) and six (last). n=6 apart from at 45:00 (session 1; n=4, session 6; n=5) and at 60:00 (session one; n=3, session six; n=4). Values are mean±SD.

3:6:2:2 Heart Rate:

Heart rate (bt·min^{-1}) recorded at 15 min intervals during acclimation / habituation sessions 1 and 6 indicated that cardiorespiratory strain tended to be similar throughout (Figure 11.). A possible explanation for not detecting differences in HR was being that after six one hour acclimation / habituation sessions in nine days participants were excessively fatigued. It could also be due to the low number of data points or the varying number of participants completing the exercise protocol.

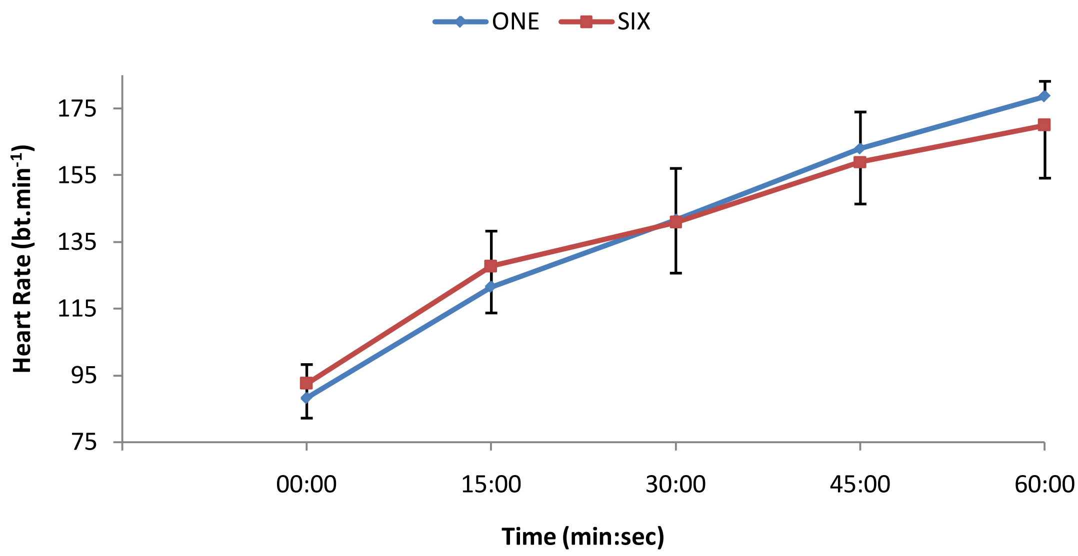

Figure 11. Heart Rate (bt·min^{-1}) responses over acclimation / habituation session one (first) and six (last). n=6 apart from at 45:00 (session 1; n=4, session 6; n=5) and at 60:00 (session one; n=3, session six; n=4). Values are mean±SD.

3:6:2:3 RPE, Thermal Sensation and Thermal Comfort:

Between the first and last acclimation / habituation sessions participants' overall and local body segment RPE declined (Table 5.). These differences conflict with HR data that indicate similar cardiovascular strain in the first and last sessions. Possibly indicating either a reduction in perception of muscular discomfort when carrying the EOD suit load or suggesting certain learning effects such as increased co-ordination are caused through repeatedly wearing the clothing ensemble. Overall RPE reduced from 17.7±1.5 (session 1) to 15.5±1.0 (session 6) after 60 min of exercise it can be concluded that only small reductions in HR are reported because of the fatiguing effect that the acclimation / habituation protocol had on participants and that the large reductions in RPE were caused through participants becoming habituated to the EOD suit and its demands.

Table 5. RPE, thermal sensation and thermal comfort during acclimation / habituation sessions one and six. n=6 apart from at 45:00 (session 1; n=4, session 6; n=5) and at 60:00 (session one; n=3, session six; n=4). Values are mean±SD. Significant main effects from a general linear model ANOVA are annotated as * (*P*<0.01) ** (*P*<0.05).

Session	**Time (min)**	**RPE**				**Thermal Sensation**					**Thermal Comfort**				
		Overall	Upper Back & Shoulders	Lower Back	Legs	Overall	Back	Chest & Arms	Groin	Legs	Overall*	Back*	Chest & Arms**	Groin**	Legs**
1	0	-	-	-	-	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4
	15	12.2±1.7	13.3±1.9	11.3±1.2	11.5±2.0	5.7±0.5	5.5±0.5	5.3±0.5	5.5±0.5	5.5±0.5	5.7±0.5	5.7±0.5	5.5±0.5	5.7±0.5	5.7±0.5
	30	13.5±1.8	15.0±2.9	12.3±1.2	12.7±1.0	6.2±0.8	6.5±0.8	5.8±0.8	5.8±0.4	5.7±0.5	6.3±1.2	6.3±1.0	5.8±1.0	5.7±0.5	5.8±0.4
	45	15.2±1.5	15.4±1.5	13.8±1.5	14.4±2.1	6.6±0.5	6.6±0.5	6.4±0.5	6.4±0.5	6.0±0.7	6.6±0.5	6.6±0.5	6.2±0.4	6.4±0.5	6.2±0.4
	60	17.7±1.5	18.3±0.6	14.3±2.1	16.7±2.3	7.0±1.0	7.3±0.6	6.7±0.6	6.7±1.2	6.3±0.6	7.3±0.6	7.7±0.6	7.0±0.0	6.7±1.2	6.3±0.6
6	0	-	-	-	-	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4
	15	12.5±0.8	12.8±0.8	11.2±0.8	11.5±1.9	5.8±0.4	5.7±0.5	5.3±0.8	5.3±0.5	5.3±0.5	5.2±0.8	5.2±0.8	4.8±0.8	4.8±0.8	4.8±0.8
	30	13.5±1.0	14.5±1.0	12.0±0.6	12.7±1.9	5.8±0.4	5.8±0.4	5.7±0.5	5.7±0.5	5.7±0.5	5.7±0.8	5.7±0.8	5.7±0.8	5.5±0.8	5.3±0.8
	45	14.4±0.9	15.8±1.3	13.4±1.1	13.8±1.5	6.2±0.4	6.6±0.5	6.4±0.5	6.0±0.7	6.2±0.8	6.3±0.5	6.3±0.5	6.2±0.4	6.0±0.7	6.0±0.7
	60	15.5±1.0	16.5±1.9	14.3±2.1	13.8±1.6	7.0±0.8	7.0±0.8	7.0±0.8	6.3±1.3	6.5±1.0	7.0±0.8	7.0±0.8	7.0±0.8	6.3±1.3	6.5±1.0

Overall and local body segment thermal sensation values tended to be lower, although not statistically significant, in session 6 compared to session 1 (Table 5.). These reductions are particularly noticeable at 15 and 30 min of exposure possibly due to the delay in the increase in T_C over 1°C already noted (Section3:6:2:1) This suggests that participant's perceptions to the similar levels of T_C decreased due to the acclimation / habituation protocol. However an habituation effect was evident from an improvement in overall ($P<0.01$; main effect) and all local body segments (back $P<0.01$, chest and arms $P<0.05$, groin $P<0.05$ and legs $P<0.05$; main effect) thermal comfort values in session 6. Again T_C was not statistically lower in this session but participants stated that felt they were more comfortable with the heat that exercise in the EOD suit created during this session compared to when they completed session 1.

3:7 Statistics

Data were managed in Microsoft Office Excel 2007. MINITAB 15 was used to conduct a general linear model analysis of variance (ANOVA) on PRE and POST acclimation / habituation data. The model incorporated main effects for condition (four conditions; 20 NS, 20 EOD, 40 NS, 40 EOD), acclimation / habituation (PRE versus POST), time, participant (n=6), interaction for condition × acclimation / habituation and interaction for condition × time. For clarity the statistical results reported in this thesis examine whether; responses were different between conditions (main effect for condition); responses varied PRE compared to POST acclimation / habituation (main effect for acclimation / habituation); whether the effect of acclimation / habituation varied between conditions (interaction for condition × acclimation / habituation). Experimental data are presented as mean (±SD) values acquired from the last 30 seconds of each stage of the activity sequence (Figure 6.). When a significant *P* value ($P \leq 0.05$) was obtained for condition or condition × acclimation a Tukey post hoc test located significant differences. Main effects are annotated as follows; * ($P \leq 0.05$), ** ($P \leq 0.01$), *** ($P \leq 0.001$) for condition and interaction effects for condition × acclimation are annotated as; $^{\#}$ ($P \leq 0.05$), $^{\#\#}$ ($P \leq 0.01$), $^{\#\#\#}$ ($P \leq 0.001$).

4 RESULTS

Data are primarily displayed to highlight differences within the same conditions PRE to POST acclimation / habituation, for example 40 EOD PRE versus 40 EOD POST acclimation / habituation and between conditions for example 20 EOD POST versus 40 EOD POST acclimation / habituation. The axes on figures are plotted with identical scales to facilitate comparisons. Changes in the magnitude of physiological and perceptual responses PRE to POST acclimation / habituation within the last activity cycle of each trial are highlighted in Table 6.

All participants completed 20 NS, 20 EOD and 40 NS trials (Table 9.). Two participants completed both PRE and POST 40 EOD trials, two of the four that did not complete the trial before acclimation / habituation completed it following the training protocol. Due to this mean tolerance time increased from 53:48±11.59 (min:sec) to 60:10±09:34 (min:sec) in 40 EOD.

4:1 Temperature Measurements

4:1:1 Rectal Temperature:

T_C increased with trial duration and was greatest in 40°C compared to 20°C trials (P<0001; main effect; Figure 12.). Acclimation / habituation reduced increases in T_C in all conditions (P<0.001; main effect). The magnitude of reduction in T_C PRE to POST was greatest in 20 EOD (0.59±0.41°C; P<0.001; Table 6.) compared to 20 NS (0.26±0.23°C; P<0.001), 40 NS (0.01±0.22°C; P<0.05) and 40 EOD

(0.08±0.14°C; P<0.01; n=2). Prior to acclimation T_C did not vary between 20 and 40 EOD trials however post acclimation T_C was lower in 20 compared to 40 EOD trials (P<0.001). for an overall measure of physiological strain refer to PSI (Section 4:3:1) and PhSI (section 4:3:2).

4:1:2 Mean Skin Temperature:

T_{SK} responses varied between conditions (P<0.001; main effect; Figure 13.). The acclimation / habituation protocol reduced T_{SK} (P<0.001; main effect) in 20 NS (0.61±0.82°C; P<0.001; Table 6.) and 20 EOD (0.42±0.45°C; P<0.001). However it did not vary PRE to POST acclimation / habituation in 40°C with or without wearing the EOD.

4:1:3 Heat Storage:

Heat stored varied between conditions (P<0.001; main effect Figure 14.). In 40°C trials participants stored more heat (P<0.001) compared to when the same clothing ensemble was worn in 20°C (40 EOD versus 20 EOD and 40 NS versus 20 NS). Acclimation / habituation reduced (P<0.001; main effect) levels of heat stored in 20 EOD (1.2±0.96 $J \cdot g^{-1}$; P<0.001; Table 6.), 40 NS (0.27±1.29 $J \cdot g^{-1}$; P<0.001) and 40 EOD (0.33±0.19 $J \cdot g^{-1}$; P=0.02; n=2). No acclimation / habituation effect in heat storage is seen in 20 NS (Table 6.).

Table 6. PRE to POST acclimation/habituation differences in key variables during the final cycle of each trial. HR, PSI, PhSI, $\dot{V}O_2$, $\dot{V}E$, RPE, Thermal Sensation, Thermal Comfort and PeSI differences compared during arm ergometry. $\dot{V}O_2$ in 40 EOD is compared from the third cycle due to the sampling line detaching from the breath by breath system in the forth cycle in participant number 3. T_C and T_{SK} and Heat Storage values are compared at the rest stage within the activity cycle(Figure 6). n=6 unless otherwise stated. ↓ denotes overall reduction, ↑ denotes overall increase and ↔ denotes no change in the individual variable. Main effects for condition are annotated as follows; *** ($P \leq 0.001$). Differences PRE to POST acclimation / habituation within each conditions (e.g. 40 EOD PRE versus 40 EOD POST) were located via Tukey post hoc tests are annotated as follows $^{\#}$ ($P \leq 0.05$), $^{\#\#}$ ($P \leq 0.01$), $^{\#\#\#}$ ($P \leq 0.001$).

Variable	20 No Suit	20 EOD	40 No Suit	40 EOD
Rectal Temp (°C)***	↓$^{\#\#\#}$(0.26±0.23)	↓$^{\#\#\#}$(0.59±0.41)	↓$^{\#}$(0.01±0.22)	↓$^{\#\#}$(0.08±0.14) n=2
Mean Skin Temp (°C)***	↓$^{\#\#\#}$(0.61±0.82)	↓$^{\#\#\#}$(0.42±0.45)	↔(0.01±0.12)	↔(-0.22±0.00) n=2
Heat Storage ($J \cdot g^{-1}$)***	↔(-0.06±0.91)	↓$^{\#\#\#}$(1.20±0.96)	↓$^{\#\#\#}$(0.27±1.29)	↓$^{\#}$(0.33±0.19) n=2
Sweat Rate ($L \cdot hr^{-1}$)***	↔(0.08±0.46)	↔(0.14±0.27)	↔(0.02±0.51)	↔(-0.20±0.44)
HR ($bt \cdot min^{-1}$)***	↓$^{\#\#\#}$(12±7)	↓$^{\#\#\#}$(29±33)	↓$^{\#\#}$(9±10)	↓$^{\#\#\#}$(6±2) n=2
$\dot{V}E$ ($L \cdot min^{-1}$)***	↔(1.0±4.5)	↓$^{\#\#\#}$(16.8±8.0)	↓$^{\#}$(6.0±5.6)	↓$^{\#\#\#}$(18.8) n=1
$\dot{V}O_2$ ($L \cdot min^{-1}$)***	↓$^{\#}$(0.08±0.13)	↓$^{\#\#\#}$(0.29±0.63)	↓$^{\#\#\#}$(0.26±0.22)	↓$^{\#\#}$(0.06±0.60) n=2
PSI***	↓$^{\#\#\#}$(0.7±0.9)	↓$^{\#\#\#}$(3.4±0.5)	↔(0.1±1.1)	↓$^{\#\#\#}$(0.5±0.1) n=2
PhSI***	↓$^{\#\#\#}$(0.6±0.6)	↓$^{\#\#\#}$(2.9±0.4)	↔(0.0±0.5)	↓$^{\#\#\#}$(1.3±1.2) n=2
RPE Overall***	↓$^{\#\#}$(1.3±2.2)	↓$^{\#\#\#}$(3.5±2.4)	↔(1.5±3.6)	↓$^{\#\#\#}$(3.5±2.1) n=2
Thermal Sensation Overall***	↓$^{\#\#\#}$(0.7±0.8)	↓$^{\#\#\#}$(2.0±0.9)	↓$^{\#}$(0.7±0.8)	↓$^{\#\#\#}$(1.0±0.0) n=2
Thermal Comfort Overall***	↑$^{\#}$(0.7±0.8)	↑$^{\#\#\#}$(2.1±1.0)	↑$^{\#\#\#}$(1.0±1.3)	↑$^{\#\#\#}$(1.0±0.0) n=2
PeSI***	↓$^{\#\#\#}$(0.9±1.1)	↓$^{\#\#\#}$(2.6±1.2)	↓$^{\#}$(1.0±1.8)	↓$^{\#\#\#}$(1.9±0.8) n=2

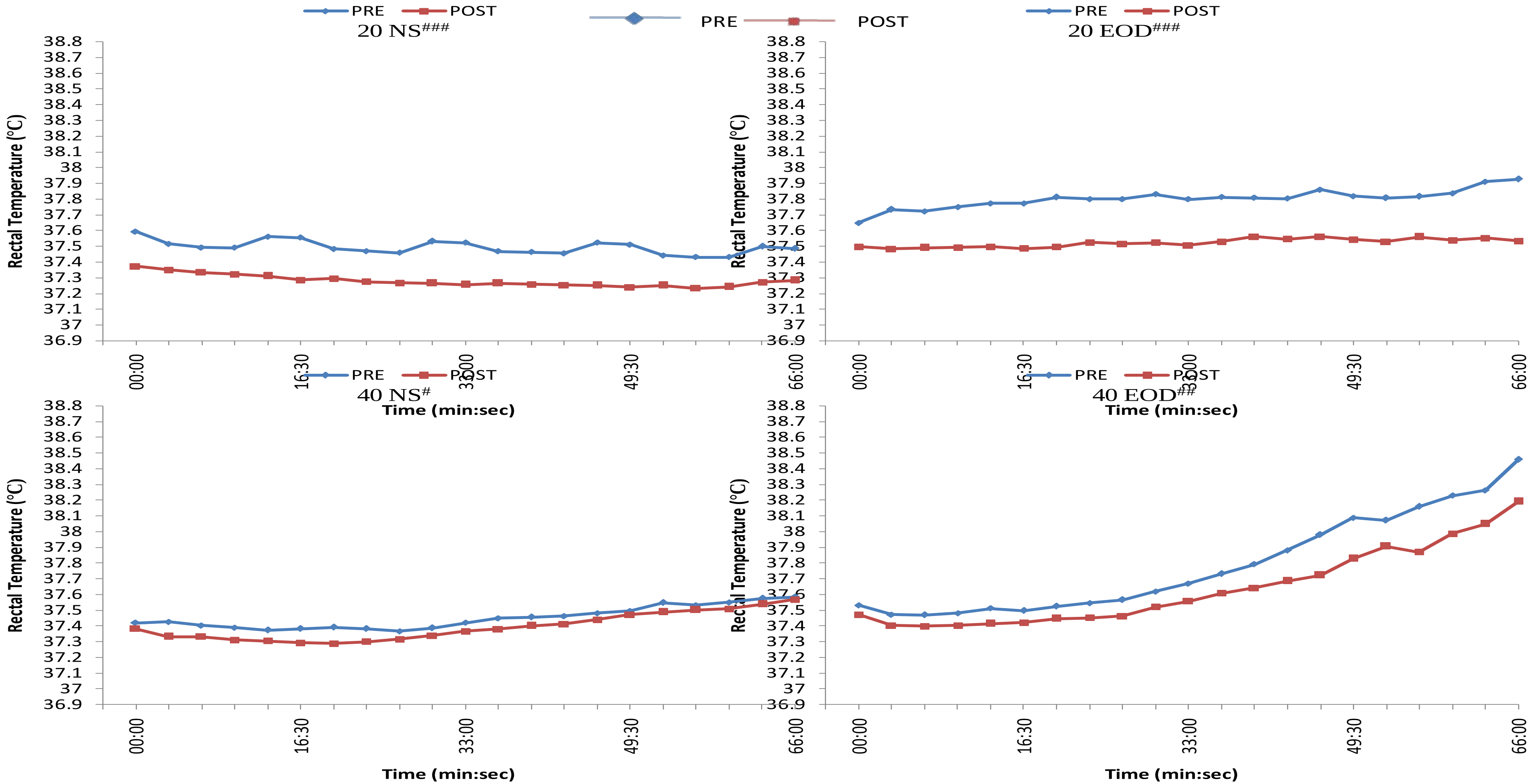

Figure 12. Rectal Temperature (°C) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from in 40 EOD at 41:00 (PRE; n=5), 44:30 (PRE; n=4, POST; n=5), 49:30 (PRE; n=4, POST; n=5), 52:30 (PRE; n=3, POST; n=5), 55:00 (PRE; n=3, POST; n=4), 57:30 (PRE; n=3, POST; n=4), 61:00 (PRE; n=2, POST; n=4), 66:00 (PRE; n=2, POST; n=4). Values are mean±SD. Differences PRE to POST acclimation / habituation were located via Tukey post hoc tests are annotated as # ($P \leq 0.05$), ## ($P \leq 0.01$), ### ($P \leq 0.001$). Main effect for condition; $P < 0.001$.

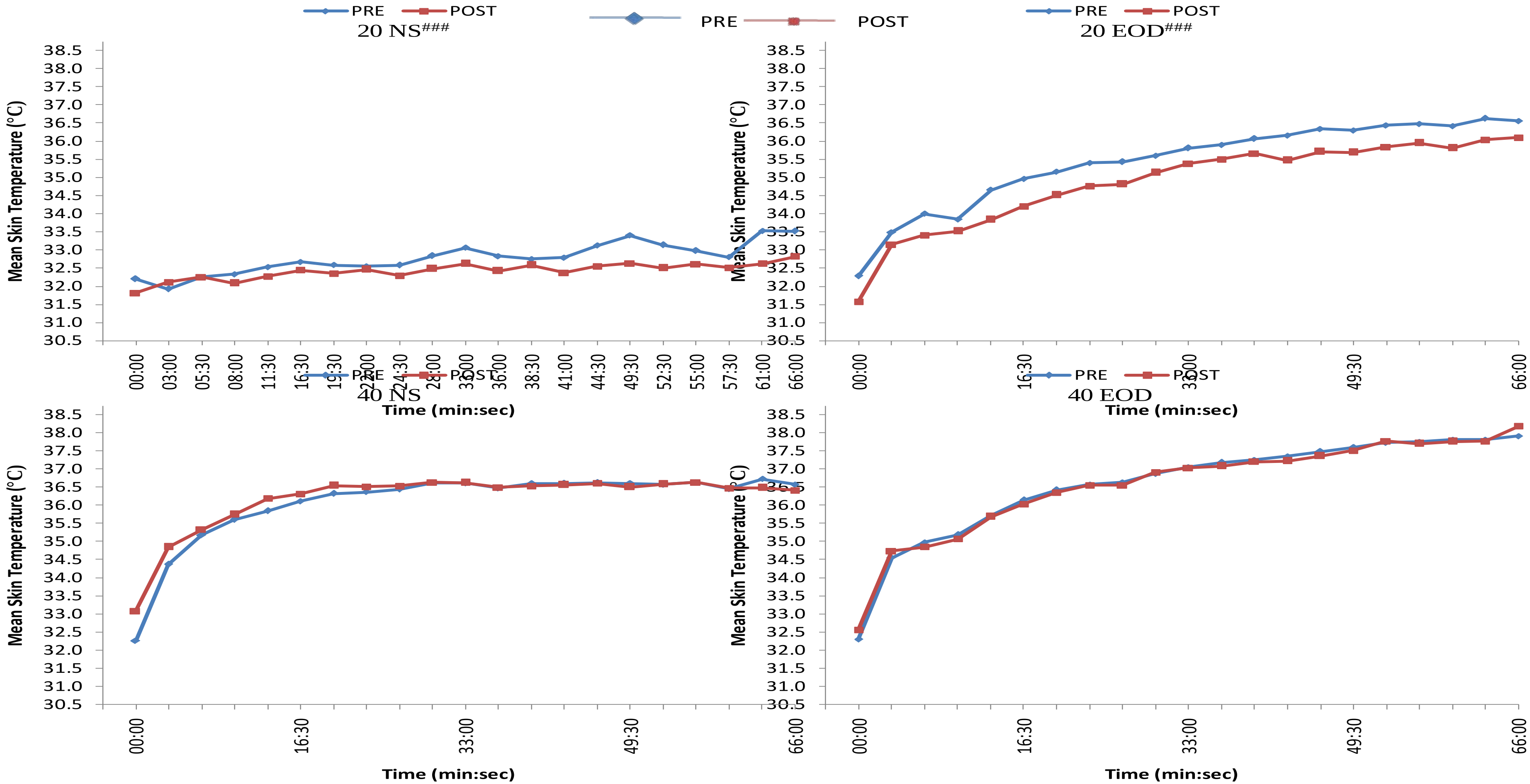

Figure 13. Mean Skin Temperature (°C) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from in 40 EOD at 41:00 (PRE; n=5), 44:30 (PRE; n=4, POST; n=5), 49:30 (PRE; n=4, POST; n=5), 52:30 (PRE; n=3, POST; n=5), 55:00 (PRE; n=3, POST; n=4), 57:30 (PRE; n=3, POST; n=4), 61:00 (PRE; n=2, POST; n=4), 66:00 (PRE; n=2, POST; n=4). Values are mean±SD. Differences PRE to POST acclimation / habituation were located via Tukey post hoc tests are annotated as ### (P≤0.001). Main effect for condition; P<0.001.

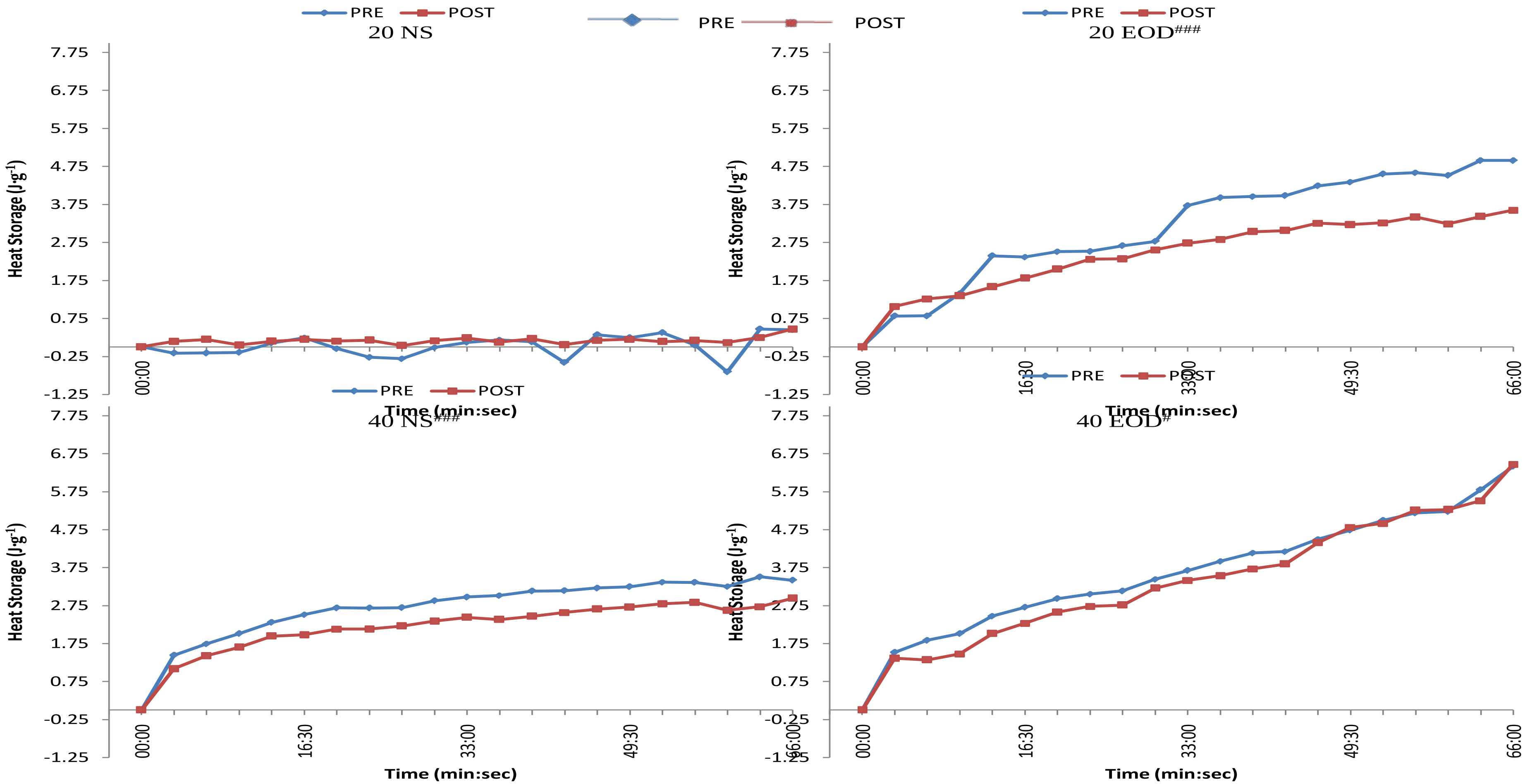

Figure 14. Heat Storage (J·g^{-1}) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from in 40 EOD at 41:00 (PRE; n=5), 44:30 (PRE; n=4, POST; n=5), 49:30 (PRE; n=4, POST; n=5), 52:30 (PRE; n=3, POST; n=5), 55:00 (PRE; n=3, POST; n=4), 57:30 (PRE; n=3, POST; n=4), 61:00 (PRE; n=2, POST; n=4), 66:00 (PRE; n=2, POST; n=4). Values are mean±SD. Differences PRE to POST acclimation / habituation were located via Tukey post hoc tests are annotated as # (P≤0.05), ### (P≤0.001). Main effect for condition; P<0.001.

4:1:4 Mean Sweat Rate:

Mean sweat rate (Figure 15.) varied between conditions (P<0.001; main effect). In both EOD and NS trials it was higher in 40°C compared to 20°C (NS; P<0.05, EOD; P<0.01; Table 6.). Mean sweat rate was not influenced by acclimation / habituation. Even so it did decrease after acclimation / habituation in 20 NS (27%; Table 6.), 20 EOD (19%) and 40 NS (2%) however it increased in 40 EOD (16%) possibly due to the increase in exposure time following acclimation / habituation.

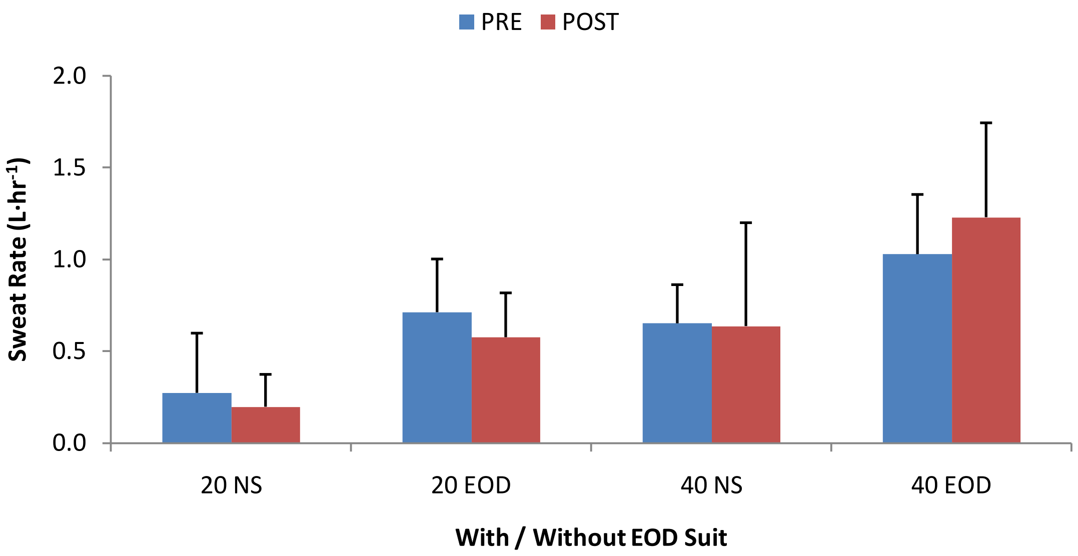

Figure 15. Mean Sweat Rate (L·hr^{-1}) over an EOD related activity sequence in 4 conditions calculated from pre and post trial nude body mass. Responses displayed are PRE and POST acclimation / habituation. Values are mean±SD. Main effect for condition; P≤0.001.

4:2 Cardiorespiratory Measurements

4:2:1 HR:

HR responses varied over the simulated activity sequence (Figure 16.) between conditions ($P<0.001$; main effect) with lower values being recorded following acclimation / habituation ($P<0.001$; main effect). The magnitude of reduction was largest in 20 EOD (29±33 bt·min^{-1}; $P<0.001$; Table 6.) compared to 20 NS (12±7 bt·min^{-1}; $P<0.001$), 40 NS (9±10 bt·min^{-1}; $P<0.01$) and 40 EOD (6±2 bt·min^{-1}; $P<0.001$; n=2). For an overall measure of physiological strain refer to PSI (Section 4:3:1) and PhSI (Section 4:3:1).

4:2:2 $\dot{V}E$:

Changes in minute ventilation (STPD) over the simulated activity sequence (Figure 17.) varied between conditions ($P<0.001$; main effect) and lower values are observed following acclimation / habituation ($P<0.001$; main effect). The greatest magnitude of reduction in $\dot{V}E$ was in 40 EOD (18.8 L·min^{-1}; $P<0.001$; Table 6.) however n=1 for this value in this condition so this value may not be a true representation of the reduction due to acclimation / habituation caused. Similar reductions were seen in 20 EOD (16.8±8.0 L·min^{-1}; $P<0.001$) compared to the reduction (6.0±5.6 L·min^{-1}; $P<0.05$) in 40 NS. Acclimation / habituation did not induce any differences in 20 NS (1.0±4.5 L·min^{-1}).

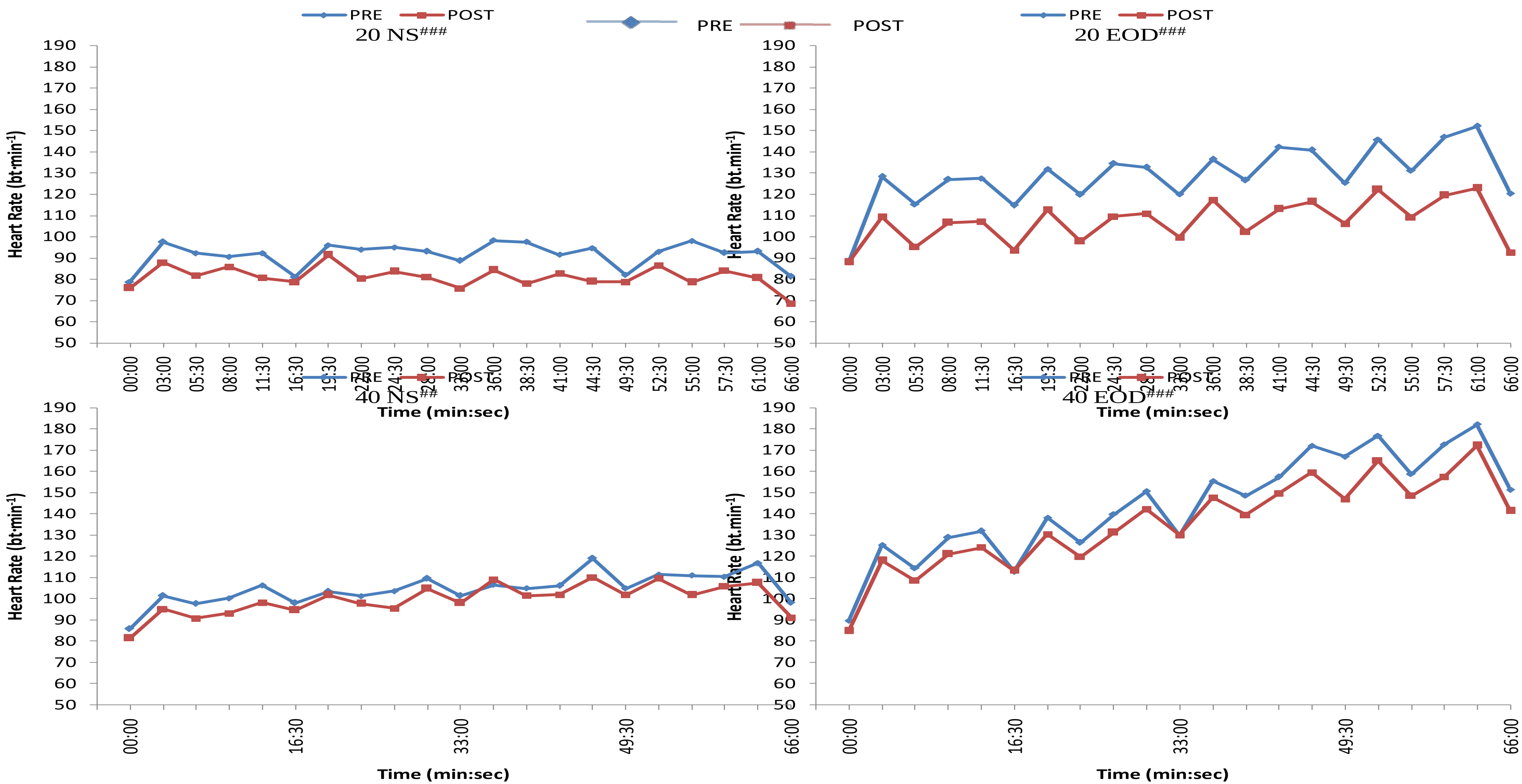

Figure 16. Heart Rate (bt·min^{-1}) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from in 40 EOD at 41:00 (PRE; n=5), 44:30 (PRE; n=4, POST; n=5), 49:30 (PRE; n=4, POST; n=5), 52:30 (PRE; n=3, POST; n=5), 55:00 (PRE; n=3, POST; n=4), 57:30 (PRE; n=3, POST; n=4), 61:00 (PRE; n=2, POST; n=4), 66:00 (PRE; n=2, POST; n=4). Values are mean±SD. Differences PRE to POST acclimation / habituation were located via Tukey post hoc tests are annotated as ## (*P*≤0.01), ### (*P*≤0.001). Main effect for condition; *P*<0.001.

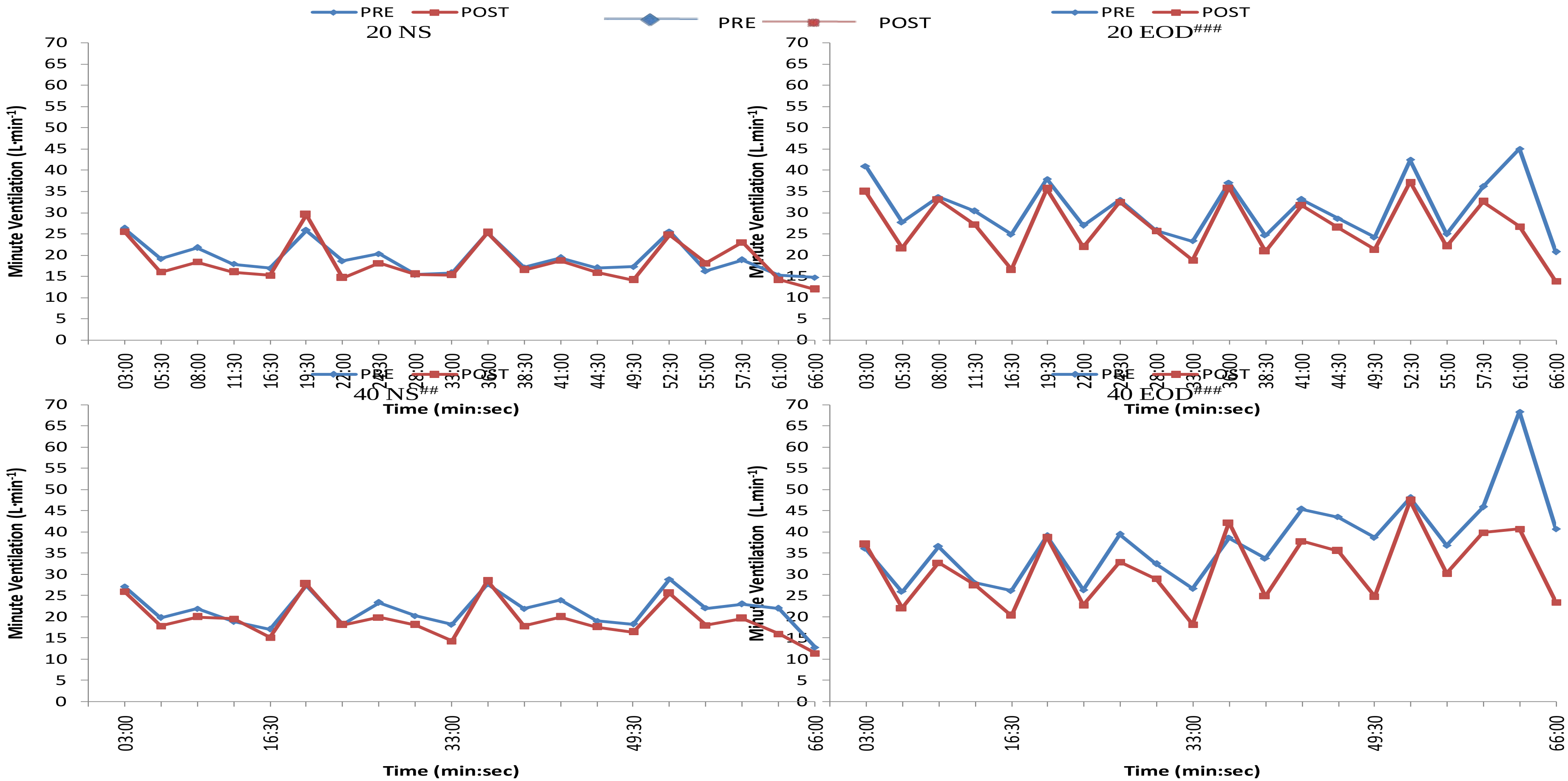

Figure 17. Minute Ventilation (V̇E; L·min^{-1}) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from 40 EOD PRE 03:00 to 38:30; n=5, 41:00 (PRE; n=4), 44:30 (PRE; n=3, POST; n=5), 49:30 (PRE; n=3, POST; n=5), 52:30 (PRE; n=2, POST; n=5), 55:00 (PRE; n=2, POST; n=4), 57:30 (PRE; n=2, POST; n=4), 61:00 (PRE; n=1, POST; n=4), 66:00 (PRE; n=1, POST; n=4). n=1 at 40 EOD PRE due to equipment malfunction. Values are mean±SD. Differences PRE to POST acclimation / habituation located via Tukey post hoc tests are annotated as ## ($P \leq 0.01$), ### ($P \leq 0.001$). Condition main effect; $P<0.001$.

4:2:3 $\dot{V}O_2$:

$\dot{V}O_2$ (STPD) varied between conditions (*P*<0.001; main effect; Figure 18; Table 6.) and decreased to a similar extent from PRE to POST acclimation / habituation in all conditions. Oxygen consumption did not vary between 20 EOD and 40 EOD and as expected the highest recorded values were seen in these trials.

4:3 Physiological Strain Calculations

4:3:1 PSI:

PSI varied between conditions (*P*<0.001; main effect; Figure 19) and declined with acclimation / habituation (*P*<0.001; main effect) to a greater extent in 20 EOD (3.4±0.5; *P*<0.001; Table 6.) compared to 40 EOD (0.5±0.1; *P*<0.001; n=2). A reduction was also noted in 20 NS (0.7±0.9; *P*<0.001) however no acclimation / habituation differences were found in 40 NS (0.1±1.1).

4:3:2 PhSI:

As expected PhSI followed the same trend as PSI. Acclimation / habituation reduced PhSI (P<0.001; main effect) by a larger extent in 20 EOD (2.9±0.4; *P*<0.001) compared to 40 EOD (1.3±1.2; *P*<0.001; n=2). Additionally values recorded in 20 NS (0.6±0.6; *P*<0.001; Table 6.) declined. As with PSI the PhSI recorded was also different between conditions (*P*<0.001; main effect; Figure 20.) and no acclimation / habituation effect was revealed in 40 NS (0.0±0.5).

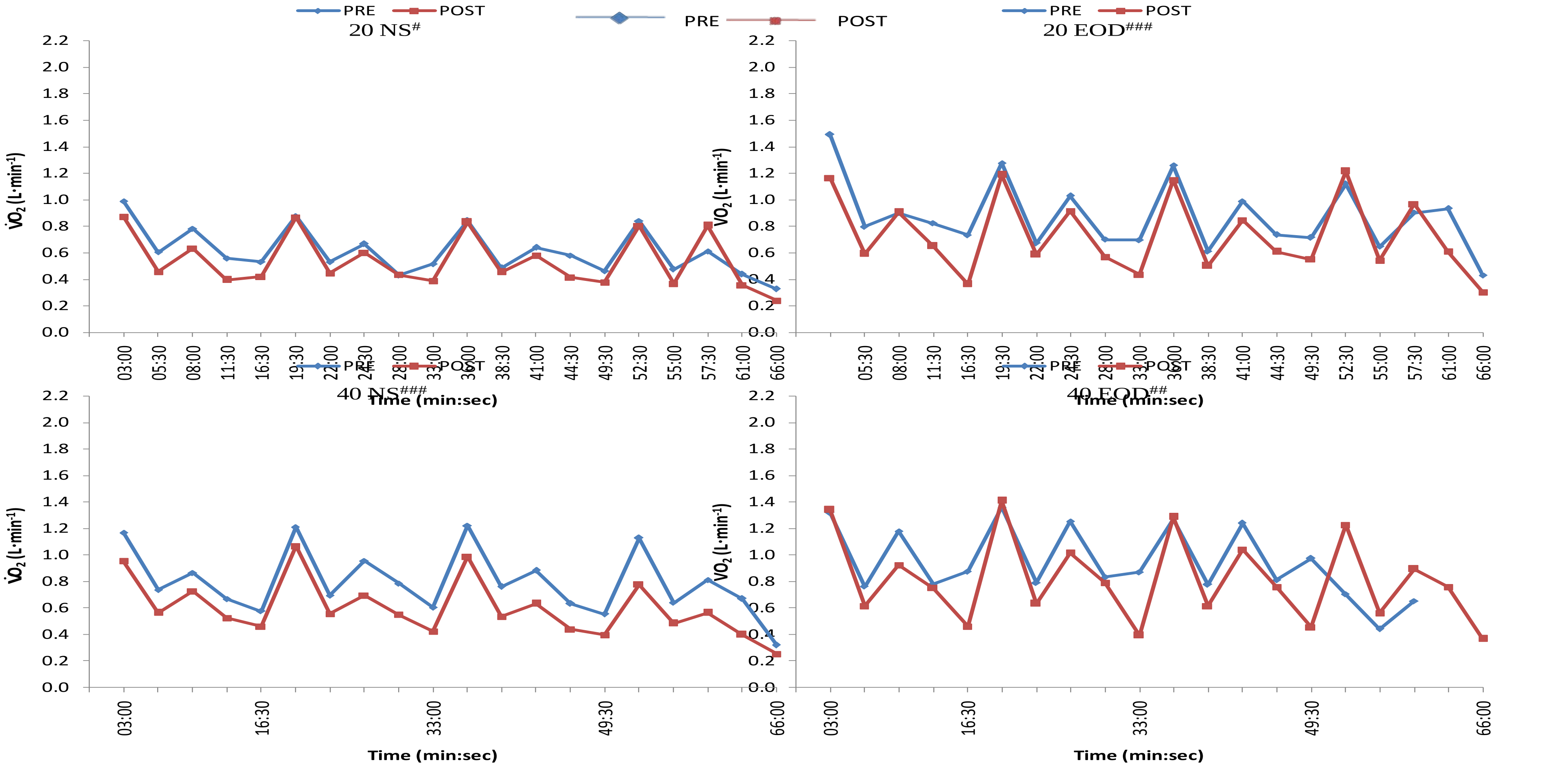

Figure 18. Oxygen Consumption (L·min^{-1}) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from in 40 EOD PRE 03:00 to 38:30; n=5, 41:00 (PRE; n=4), 44:30 (PRE; n=3, POST; n=5), 49:30 (PRE; n=2, POST; n=5), 52:30 (PRE; n=1, POST; n=5), 55:00 (PRE; n=1, POST; n=4), 57:30 (PRE; n=1, POST; n=4), 61:00 (POST; n=4), 66:00 (POST; n=4). Values are mean±SD. Differences PRE to POST acclimation / habituation were located via Tukey post hoc tests are annotated as # (P≤0.05), ## (P≤0.01), ### (P≤0.001). Main effect for condition; P<0.001.

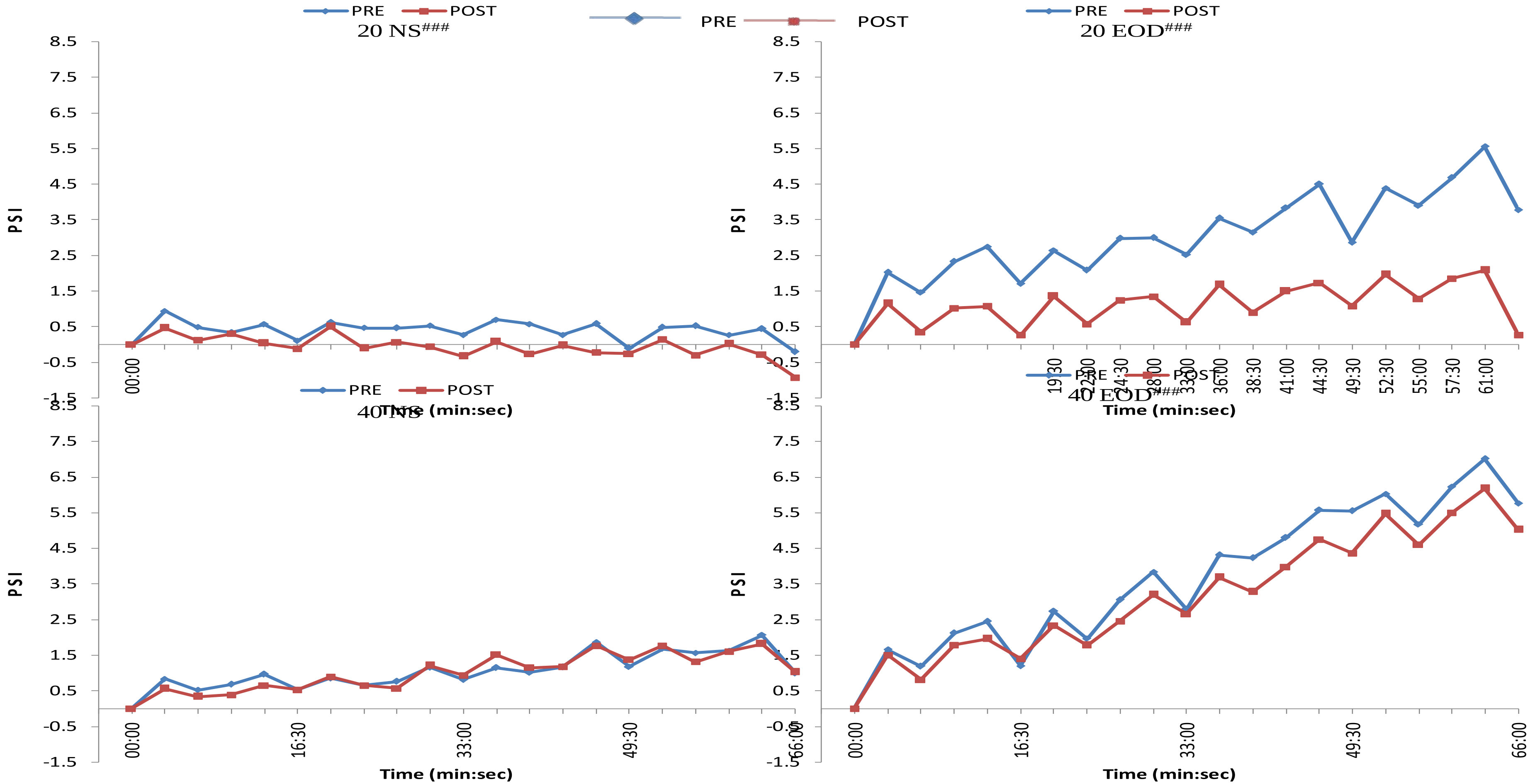

Figure 19. Physiological Strain Index (PSI) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from in 40 EOD at 41:00 (PRE; n=5), 44:30 (PRE; n=4, POST; n=5), 49:30 (PRE; n=4, POST; n=5), 52:30 (PRE; n=3, POST; n=5), 55:00 (PRE; n=3, POST; n=4), 57:30 (PRE; n=3, POST; n=4), 61:00 (PRE; n=2, POST; n=4), 66:00 (PRE; n=2, POST; n=4). Values are mean±SD. Differences PRE to POST acclimation / habituation were located via Tukey post hoc tests are annotated as ### (P≤0.001). Main effect for condition; P<0.001.

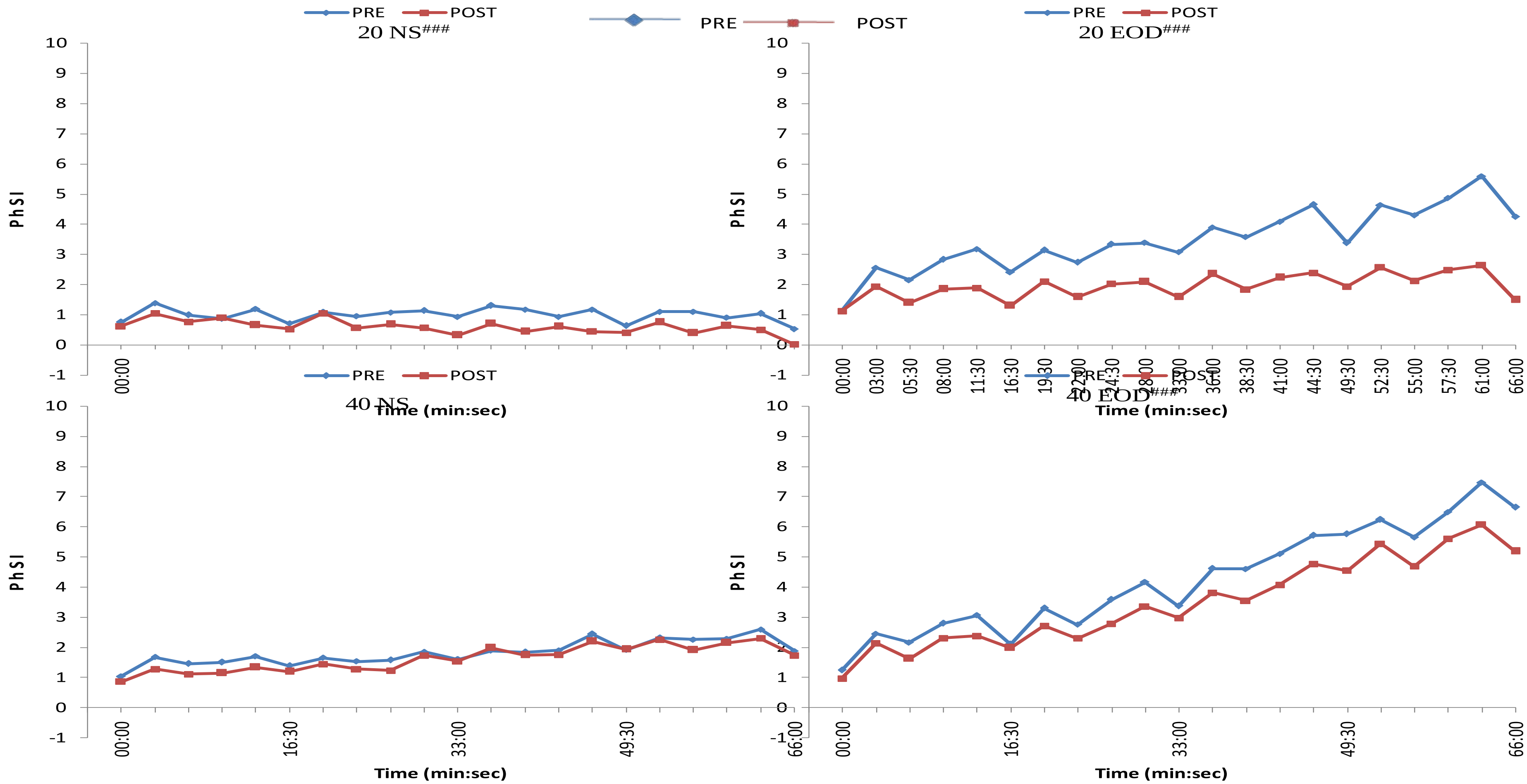

Figure 20. Adapted Physiological Strain Index (PhSI) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from in 40 EOD at 41:00 (PRE; n=5), 44:30 (PRE; n=4, POST; n=5), 49:30 (PRE; n=4, POST; n=5), 52:30 (PRE; n=3, POST; n=5), 55:00 (PRE; n=3, POST; n=4), 57:30 (PRE; n=3, POST; n=4), 61:00 (PRE; n=2, POST; n=4), 66:00 (PRE; n=2, POST; n=4). Values are mean±SD. Differences PRE to POST acclimation / habituation were located via Tukey post hoc tests are annotated as ### ($P \leq 0.001$). Main effect for condition; $P < 0.001$.

4:4 Perceptual Measurements

4:4:1 RPE:

Local and overall body RPE values (Table 7. and Appendix D) varied between conditions (P<0.001; main effect) and were lower following acclimation / habituation (P<0.001; main effect). Whole body RPE declined (Table 6.) by the greatest magnitude in 20 EOD (3.5±2.4; P<0.001) and 40 EOD (3.5±2.1; P<0.001; n=2) compared to reductions seen in 20 NS (1.3±2.2; P<0.01) during the final cycle. Only a tendency for a reduction in whole body RPE is seen in 40 NS (1.5±3.6; P=0.068). This reflects the observed magnitude of reduction in HR, $\dot{V}O_2$ and physiological strain already noted.

4:4:2 Thermal Sensation:

Both perceived local and overall body thermal sensation (Table 8. and Appendix D) varied between conditions (P<0.001; main effect) and were lower following acclimation / habituation (P<0.001; main effect). The greatest reductions in overall thermal sensation, noted during the final cycle, were observed in 20 EOD (2.0±0.9; P<0.001; Table 6.) compared to 20 NS (0.7±0.8; P<0.001) and 40 EOD (1.0±0.0; P<0.001; n=2). Acclimation / habituation also reduced overall (0.7±0.8; P<0.05) and back (0.6±0.8; P<0.01) thermal sensation in 40 NS however no change was apparent in the values reported for the chest and arms, groin and legs.

Table 7. PRE and POST acclimation / habituation differences in RPE (mean±SD) over an EOD related activity sequence in 4 conditions. The first protocol stage, in the first cycle where RPE is taken is during the treadmill stage. The last protocol stage, in the forth cycle (Figure 6.), RPE is taken during arm ergometry. n=6 apart from in 40 EOD PRE Cycle 4 (n=2) and 40 EOD POST Cycle 4 (n=4). Main effects for condition are annotated as; *** ($P \leq 0.001$). Differences PRE to POST acclimation / habituation compared within the same condition located via Tukey post hoc tests are annotated as # ($P \leq 0.05$), ## ($P \leq 0.01$), ### ($P \leq 0.001$).

Condition	Cycle	RPE			
		Overall* **	**Upper Back & Shoulders*** **	**Lower Back*** **	**Legs*** **
20 No Suit PRE	**1**	7.2±0.4	7.2±0.8	7.0±0.7	7.4±0.9
	4	9.3±1.6	8.8±1.5	8.7±1.4	9.0±1.5
20 No Suit POST	**1**	7.0±0.9	7.0±0.9	6.7±0.8	7.0±0.9
	4	8.0±1.7##	7.8±1.7#	7.2±0.8###	7.5±1.4##
20 EOD PRE	**1**	10.8±1.5	12.3±1.0	11.3±0.8	11.3±1.4
	4	15.5±1.8	16.3±2.3	14.2±1.7	13.2±1.8
20 EOD POST	**1**	9.7±2.3	10.3±2.5	8.7±1.6	9.3±2.4
	4	12.0±2.1###	13.0±2.6###	11.0±1.6###	11.0±2.1###
40 No Suit PRE	**1**	7.5±1.2	7.2±1.2	7.3±1.4	7.7±2.1
	4	11.0±2.5	10.8±3.1	10.0±3.4	10.2±2.5
40 No Suit POST	**1**	8.2±1.7	7.8±1.7	7.2±1.5	8.3±2.3
	4	9.5±2.3	9.0±2.2	8.0±1.1###	8.8±2.2
40 EOD PRE	**1**	12.0±1.0	13.0±1.1	11.0±1.0	11.0±1.0
	4	19.0±0.0	19.3±0.6	16.0±2.0	16.0±2.0
40 EOD POST	**1**	9.8±1.2	10.5±1.6	9.0±1.4	9.3±2.1
	4	16.8±1.9###	17.0±2.0###	13.5±3.7###	14.5±4.4###

Table 8. PRE and POST acclimation differences in thermal sensation and thermal comfort (mean±SD) over an EOD related activity sequence in 4 conditions. The first stage, in the first cycle, variables are taken during arm ergometry. The final stage in the fourth cycle variables are taken during the rest stage (Figure 6.). n=6 apart from in 40 EOD PRE Cycle 4 (n=2) and 40 EOD POST Cycle 4 (n=4). Main effects for condition are annotated as; *** ($P \leq 0.001$). Differences PRE to POST acclimation / habituation compared within the same condition located via Tukey post hoc tests are annotated as $^{\#}$ ($P \leq 0.05$), $^{\#\#}$ ($P \leq 0.01$), $^{\#\#\#}$ ($P \leq 0.001$).

Condition	Cycle	Thermal Sensation					Thermal Comfort				
		Overall***	Back***	Chest & Arms***	Groin***	Legs***	Overall***	Back***	Chest & Arms***	Groin***	Legs***
20 No Suit PRE	**1**	4.0±0.9	3.8±0.8	3.8±0.8	3.7±0.5	3.7±0.5	4.0±0.6	4.0±0.6	4.0±0.6	3.8±0.4	3.8±0.4
	4	4.0±1.1	4.3±1.2	4.0±1.1	3.8±0.8	4.0±0.9	4.2±1.0	4.3±1.0	4.2±1.0	4.0±0.6	4.0±0.6
20 No Suit POST	**1**	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5
	4	3.5±0.5$^{\#\#\#}$	3.5±0.5$^{\#\#\#}$	3.5±0.5$^{\#}$	3.5±0.5$^{\#}$	3.7±0.8$^{\#}$	3.7±0.5$^{\#}$	3.7±0.5$^{\#\#\#}$	3.7±0.5$^{\#}$	3.7±0.5	3.7±0.5
20 EOD PRE	**1**	5.3±0.5	5.7±0.8	5.7±0.8	5.2±0.4	4.8±1.5	5.7±0.5	5.0±1.0	5.0±0.9	5.0±0.6	4.8±1.0
	4	6.7±0.8	6.7±0.8	6.5±0.8	6.0±0.6	6.2±0.8	6.7±1.0	7.0±0.8	6.5±0.8	6.2±0.8	6.2±1.8
20 EOD POST	**1**	4.0±0.6	4.0±0.6	3.8±0.4	4.0±0.6	4.0±0.6	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4
	4	4.3±0.5$^{\#\#\#}$	4.7±0.8$^{\#\#\#}$	4.7±0.8$^{\#\#\#}$	4.3±0.6$^{\#\#\#}$	4.3±0.5$^{\#\#\#}$	4.5±0.8$^{\#\#\#}$	4.7±1.0$^{\#\#\#}$	4.5±0.8$^{\#\#\#}$	4.3±0.5$^{\#\#\#}$	4.3±0.5$^{\#\#\#}$
40 No Suit PRE	**1**	5.0±0.6	4.8±0.4	4.8±0.8	4.7±0.5	4.5±0.5	4.8±0.8	5.0±1.0	4.7±0.8	4.5±0.5	4.3±0.5
	4	6.0±0.6	6.0±0.6	5.5±0.8	5.7±0.8	5.5±0.8	6.0±1.1	6.0±1.0	5.7±1.2	5.7±0.8	5.7±0.8
40 No Suit POST	**1**	4.5±0.5	4.3±0.5	4.5±0.5	4.3±0.5	4.2±0.4	4.2±0.4	4.2±0.4	4.2±0.4	4.2±0.4	4.2±0.4
	4	5.2±0.4$^{\#}$	5.2±0.4$^{\#\#}$	5.0±0.6	5.2±0.4	5.2±0.4	4.8±0.8$^{\#\#\#}$	4.8±0.8$^{\#\#\#}$	4.8±0.8$^{\#\#\#}$	4.8±0.8$^{\#\#\#}$	4.8±0.8$^{\#}$
40 EOD PRE	**1**	6.0±0.6	6.0±0.6	6.0±1.0	6.0±1.0	6.0±1.0	6.0±1.0	6.0±0.0	6.0±1.0	6.0±1.0	6.0±1.0
	4	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0
40 EOD POST	**1**	5.2±0.4	5.0±0.0	5.0±0.6	4.8±0.4	4.8±0.4	5.2±0.4	5.0±0.0	5.0±0.6	4.8±0.4	4.7±0.5
	4	6.8±1.0$^{\#\#\#}$	7.0±0.8$^{\#\#\#}$	6.5±1.3$^{\#\#\#}$	6.8±1.0$^{\#\#\#}$	6.8±1.0$^{\#\#\#}$	6.8±1.0$^{\#\#\#}$	7.0±0.8$^{\#\#\#}$	6.8±1.0$^{\#\#\#}$	6.8±1.0$^{\#\#\#}$	6.8±1.0$^{\#\#\#}$

4:4:3 Thermal Comfort:

Condition (P<0.001; main effect) and acclimation / habituation (P<0.001; main effect) differences were observed in local and whole body perceived thermal comfort (Table 8. and Appendix D). Acclimation / habituation reductions are consistent throughout all whole and local body segments in 20 EOD (overall; 2.1±1.0; P<0.001; Table 6.) and 40 EOD (overall; 1.0±0.0; n=2 P<0.001; n=2). Acclimation / habituation also improved thermal comfort values in 40 NS (whole body; 1.0±1.3; P<0.001) apart from the legs (P<0.05). Reductions in 20 NS (whole body; 0.7±0.8; P<0.05) are seen in all areas apart from the legs, where a tendency was noted (P=0.06) and the groin where no reductions were seen.

4:5 Perceptual Strain Calculations

Perception based strain (Figure 21. and Appendix D) increased with trial duration and varied between conditions (P<0.001; main effect). Acclimation / habituation also reduced PeSI (P<0.001; main effect) and the magnitude of this reduction is largest in 20 EOD (2.6±1.2; P<0.001; Table 6.) compared to 40 EOD (1.9±0.8; P<0.001). Additionally values recorded in both 20 NS (0.9±1.1; P<0.001) and 40 NS (1.0±1.8; P<0.05) decreased following acclimation / habituation (Table 6.).

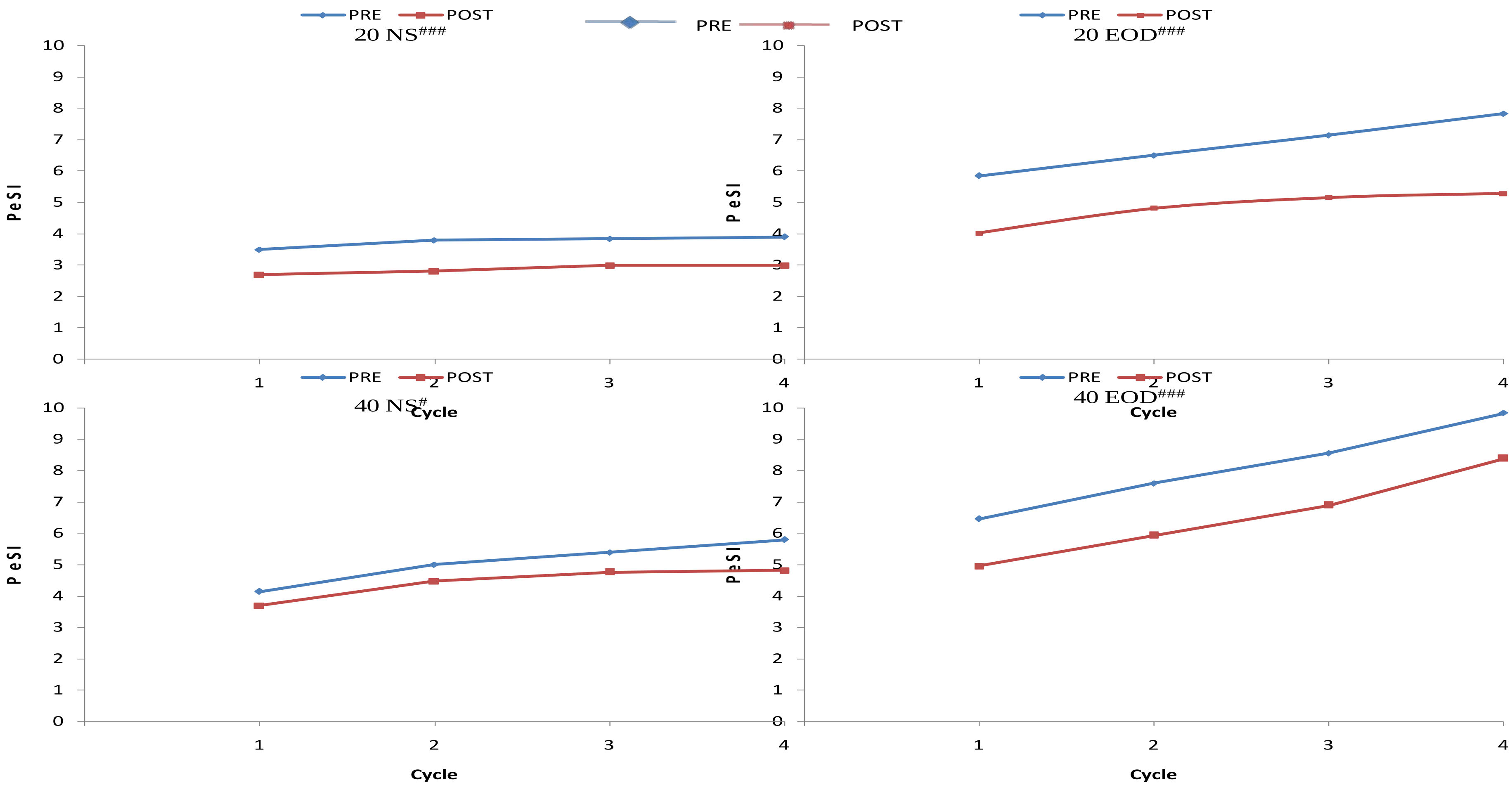

Figure 21. Perception based Strain Index (PeSI) responses over an EOD related activity sequence in 4 conditions. Responses displayed are PRE and POST acclimation / habituation. n=6 apart from in 40 EOD PRE Cycle 3 (PRE; n=3, POST; n=5) and Cycle 4 (PRE; n=2, POST; n=4). Values are mean±SD. Differences PRE to POST acclimation / habituation were located via Tukey post hoc tests are annotated as # ($P \leq 0.05$), ### ($P \leq 0.001$). Main effect for condition; $P < 0.001$.

4:6 General Symptoms Questionnaire Scores

Scores recorded from the general symptoms questionnaire (Table 9.) declined from trial totals of 10 and 18 in PRE 20 EOD and 40 EOD respectively o 0 and 9 in the corresponding POST trials. Participants stated that the acclimation / habituation protocol eliminated any feeling of light headedness, tiredness and difficulty breathing in 20 EOD. The protocol also reduced perceived levels of light headedness, difficulty breathing, sickness and headache in 40 EOD while also reducing any feeling of tiredness.

4:7 Summary of Results

Reductions in physiological and perceptual variables were seen in all conditions following acclimation / habituation however the largest change was seen in 20 EOD; where reductions were observed in all variables apart from mean sweat rate. This indicates that the acclimation / habituation protocol employed makes work in the EOD suit feel 'easier' due to physiological and perceptual adaptations associated with repeated exposures. These data suggest that reductions in cardiovascular (HR) and metabolic ($\dot{V}O_2$ and $\dot{V}E$) responses to the activity sequence contributed to decreased thermal (T_C, T_{SK} and heat storage) strain resulting in improved perceptual (RPE, thermal sensation and thermal comfort) variables when conducting an EOD related activity sequence whilst wearing the EOD suit. These trends are summarised by PSI, PhSI (Section 4:3) and PeSI (Section 4:5) values and of interest is the larger reduction in PeSI compared to the reductions in PhSI in all conditions.

Table 9. General Symptoms Questionnaire (GSQ) scores and Exercise-Heat Tolerance Times (min:sec) from an EOD related activity sequence in 4 conditions. GSQ scores are the total of cumulative values for all participants reported over individual trials.

	General Symptoms Questionnaire Scores							**Tolerance Time (min:sec)**
	Headache	Sickness	Light Headedness	Mentally Confused	Tiredness	Difficulty Breathing	Trial Total	
20 No Suit PRE	0	0	0	0	1	0	1	66:00±00:00
20 No Suit POST	0	0	0	0	0	0	0	66:00±00:00
20 EOD PRE	0	0	3	0	3	4	10	66:00±00:00
20 EOD POST	0	0	0	0	0	0	0	66:00±00:00
40 No Suit PRE	0	0	0	0	3	0	3	66:00±00:00
40 No Suit POST	3	0	1	0	0	0	4	66:00±00:00
40 EOD PRE	4	3	4	0	3	4	18	53:48±11:59
40 EOD POST	3	1	3	0	0	2	9	60:10±09:34

In 40 EOD no acclimation / habituation effect was observed for T_{SK} and mean sweat rate and reductions in T_C, heat storage, HR and VO_2 are to as less magnitude than those seen in 20 EOD. Also, of operational interest is the large increase in PSI and PhSI visible from the third activity cycle onwards. Acclimation / habituation reduced values but a large increase in physiological strain from this time point is still visible.

When the EOD suit was not worn in 20°C no acclimation / habituation effect was evident in heat storage, $\dot{V}E$ and mean sweat rate. The magnitude of reduction in $\dot{V}O_2$, RPE and thermal comfort were also to a lesser magnitude to that seen in 20 EOD. Where acclimation / habituation had the least effect was in 40 NS. No observed reduction was seen in T_{SK}, physiological strain (PSI and PhSI) and RPE in this trial however some degree of change in thermal comfort was noted but this change in perception was the weakest seen between the four conditions. All other variables did not change to the same extent as those seen in 20 EOD.

5 DISCUSSION

Six one hour treadmill walks at 20°C ambient temperature whilst wearing an EOD suit (with no active ventilation engaged) resulted in considerable reductions in participant T_C and HR responses as well as perceptual and thermal indices whilst conducting activities representative of EOD operations in both 20° and 40°C (Table 6.). The magnitude of reduction in physiological and perceptual strain was however greatest in 20 compared to 40°C EOD trials. $\dot{V}O_2$ declined from PRE to POST acclimation / habituation during all EOD and NS trials therefore reduced heat strain may potentially be accounted for by improved economy as well as thermoregulatory adaptations. In summary, to the authors knowledge this is the first study to demonstrate that training whilst wearing PPE in temperate conditions (20°C) reduces both physiological and perceptual responses during an occupationally relevant activity in a temperate environment and that these responses are transferable, albeit to a limited extent, in a hot environment where the temperature is in excess of skin temperature.

The following section will compare and contrast the magnitude of change in physiological responses to EOD related activity before and after acclimation / habituation (Section 5:1). This will be followed by a more thorough examination of component variables (Section 5:2) and perceptual responses (Section 5:3). The final sections will discuss the experimental design (Section 5:4) and the potential operational recommendations that should be considered in light of these findings (Section 5:5).

5:1 Changes in Physiological Responses to EOD Related Activity Following Acclimation / Habituation

The extent that acclimation / habituation is taken up by participants is gauged by the reductions it causes in two key physiological variables, HR and T_C, during heat stress tests (Cheung, McLellan and Tenaglia 2000). In this study HR in 20 EOD was reduced by 29±33 bt·min^{-1} and by 6±2 bt·min^{-1} in 40 EOD (Table 10.) at the end of the forth and last activity cycle. Other acclimation / habituation research have also reported a reduction in HR (Table 10.). For example during intermittent heat stress tests (repeated 15 min treadmill walking at 1.33 m·s^{-1} followed by 15 min seated rest until volitional exhaustion) while wearing NBC clothing, McLellan and Aoyagi (1996) noted a 10–15 bt·min^{-1} reduction in HR with acclimation in relatively fit non-acclimated males (Table 10.). This is seen following 12 acclimation sessions, completed over a two week period with one rest day each week in 40°C, 30% RH, where T_C was maintained through an exercise protocol of treadmill walking, at 1.3°C above baseline level for 60 min when wearing the NBC garment.

Cheung and McLellan (1998a) assessed changes seen in final HR between sessions 1 and 10 of their acclimation / habituation protocol (Table 10.). Reductions were found in both a highly ($\dot{V}O_{2peak}$ > 55 ml·kg·min^{-1}; n=8) and moderately fit ($\dot{V}O_{2peak}$ < 50 ml·kg·min^{-1}; n=7) population however the largest reduction was found with highly fit (156±14 bt·min^{-1} to 147±15 bt·min^{-1}) individuals compared to the moderately fit (167±15 bt·min^{-1} to 160±19 bt·min^{-1}). Although only small differences are noted this data supports claims that individuals with a higher $\dot{V}O_{2peak}$ are more capable of gaining the physical advantages that heat acclimation causes (Nadel,

Table 10. A comparison of the magnitude of adaptation achieved during studies where a protective clothing ensemble was worn during acclimation / habituation sessions. MF denotes moderately fit ($\dot{V}O_{2peak}$ < 50 ml·kg·$^{-1}$min^{-1}), HF denotes highly fit ($\dot{V}O_{2peak}$ > 55ml·kg·$^{-1}$min.$^{-1}$) * denotes $P\leq0.05$, ** denotes $P\leq0.01$, *** denotes $P\leq0.001$.

Study	Participants	Acclimation / Habituation Protocol	Experimental Trial Protocol	HR Changes (bt·min^{-1})	T_C Changes (°C)
Current Study	5 male, 1 female University Students	6, 60 min treadmill walking (4 km·hr^{-1}) sessions ≈ 20°C, EOD suit worn	66 min simulated bomb disposal activity in 20° and 40°C with and without wearing EOD suit	20 EOD = 29±33*** difference 40 EOD = 6±2 (n=2)*** difference, (PRE = 182±4; n = 2, POST; 172±9; n=4)	20 EOD = 0.59±0.41*** difference 40 EOD = 0.08±0.14** (n=2) difference, (PRE = 38.46±0.28; POST = 38.19±0.33; n=4)
Cheung and McLellan (1998a)	Military personnel and university students (n=15) some subjects already familiar with NBC clothing	2x5 days (separated by 2 days) (40°C, 30% RH) 60 min treadmill walking (4.8 km·hr^{-1}, 3-7% gradient, NBC worn.	Measurements compared between 1st and final acclimation sessions	MF = 167.3±15.1 to 159.9±19.0*(final HR) HF = 156.1±13.6 to 146.9±15.3*(final HR)	MF = 38.70±0.24 to 38.53±0.15 (final T_C) HF = 38.75±0.23 to 38.54±0.20* (final T_C)
McLellan and Aoyagi (1996)	Non-acclimated males (n=22) (mean $\dot{V}O_{2peak}$; 48 ml·kg·min^{-1})	12, 1 hr treadmill walking sessions in 40°C, 30% RH, NBC ensemble worn, T_C maintained at 1.3°C above baseline measurement.	100 min intermittent (15 min exercise, 15 min rest) treadmill walking (1.33 m.s^{-1}), 40°C, 30% RH.	10 to 15 bt·min^{-1*} reduction over trials	Time to increase 1°C; PRE = 66.8±5.1 (min) POST = 82.3±6.3 (min)*
Shvartz, Saar, Meyerstein *et al.* (1973)	Males (n=9)	6 days, 37°C, moderate work, vapour barrier suit worn.	Measurements compared between acclimation session 1 and 6.	16 bt·min^{-1} reduction at corresponding exhaustion time (recorded from session 1)	0.3°C reduction at rest and 0.5°C reduction at corresponding exhaustion time (recorded from session 1)

Pandolf, Roberts *et al.* 1974). Shvartz, Saar, Meyerstein *et al.* (1973) also addressed the magnitude of HR change due to acclimation / habituation between the first (1) and last (6) exposure sessions. They reported that repeated heat (37°C) exposures while completing bench stepping exercise (15 times per min; 27.5 cm high) in a vapour barrier suit caused a 16 $bt \cdot min^{-1}$ reduction in HR over session 6 compared to session 1 (Table 10.). These reductions in HR values resulted from an improved thermal response to heat exposure. Acclimation / habituation increases plasma volume (Harrison 1985). It also enables stroke volume to be maintained and therefore cardiac output during exercise in the heat (Nielsen, Hales, Strange et al. 1993). Due to the reduced relative decline in plasma volume and therefore stroke volume HR does not need to increase to such a large magnitude to maintain arterial blood pressure and skin blood flow (Hargreaves 2008). Lower HR at a given load of work reduces metabolic heat production and is indicative of relative decrease in sympathetic nervous system activity.

Lower T_C values over the activity sequence in this investigation were observed in 20 and 40 EOD POST compared to PRE trials. Values measured at the end of the sequence show a 0.59±0.41°C reduction in 20 EOD and a smaller reduction in the 40 EOD (0.08±0.14°C; n=2; Table 10.). McLellan and Aoyagi (1996) depict changes in T_C over PRE and POST acclimation heat stress tests as the time it takes to increase 1°C above baseline (Table 10.). From wearing NBC clothing during acclimation / habituation sessions an increase in this time from 66.8±5.1 (min) to 82.3±6.3 (min) was observed. During acclimation / habituation session 1 in the present research a 1°C rise in T_C was observed after 23:12±13.22 (min:sec) of exposure and in session 6 this time was increased to 30:45±14:56 (min:sec). However during both 20 and 40 EOD

PRE and POST trials mean T_C did not increase 1°C above of its resting value possibly because the intermittent activity sequence was only 66 min in duration and the suits fan cooling system was turned on which could have increased conductive and convective cooling to limit increases in T_C. Despite this reductions in the rise of T_C were seen in both the 20 (PRE = 0.57±0.22°C; POST = 0.05±0.07°C) and 40 (PRE = 0.95±0.35°C; POST = 0.79±0.24°C) EOD. A smaller reduction is possibly observed in 40 EOD because of the fan system actually contributing to heat gain via circulating 40°C ambient air around the suit which is noticeable during the first cycle of the activity sequence as demonstrated by an increased rate of rise in T_{SK} in 40 EOD (PRE = 3.84°C, POST = 3.48°C) compared to 20 EOD trials (PRE= 2.69°C, POST = 2.64°C).

Shvartz, Saar, Meyerstein *et al*. (1973) report a reduction in T_C of 0.5°C between the first and final exposure sessions of their acclimation / habituation protocol (Table 10.). This T_C value is greater than the 10 day acclimation / habituation protocol used by Cheung and McLellan (1998a). Final T_C in a moderately fit population reduced from 38.70±0.24°C to only 38.53±0.15°C, which was not statistically significant. In a highly fit population, where the benefits of acclimation should be more visible, a small reduction from 38.75±0.23°C to 38.54±0.20°C was observed. Statistical analysis showed that these differences were significant however the data shows that the T_C differences are not that large and the magnitude of the reduction in the two populations again is not that different (Table 10.). No real difference in aural temperature is also reported in the current research between the first and sixth acclimation / habituation sessions following 60 min of exercise. But the small differences in final T_C reported by Cheung and McLellan (1998a) were accompanied with in decrease in cardiovascular strain and an enhanced sweat response, seen via a decrease in final HR and increased sweat rate, in both populations.

The physical changes reported in research conducted by Cheung and McLellan (1998a) and Shvartz, Saar, Meyerstein *et al.* (1973) are seen when participants completed exercise in a single mode during acclimation / habituation sessions (Table 10.). However procedures used were not a valid representation of the intermittent activities that operatives regularly undertake in the field. Although, in this research, during acclimation / habituation sessions only one mode of exercise was completed an intermittent EOD related activity sequence was completed in four conditions prior to and following acclimation / habituation. This created a valid representation of the actions regularly undertaken by operatives in the field and allowed for PRE to POST physiological and perceptual comparisons to be made.

It is also important to assess the impact that carrying the EOD load has on physiological and perceptual strain compared to other pieces of PPE that have a lighter mass. Tikuisis, McLellan and Selkirk (2002) assessed the magnitude of physiological and perceptual strain that wearing a military biological and chemical protective ensemble (combat clothing, semi-permeable overgarment, impermeable rubber boots and gloves, respirator and canister) had on participants completing continuous treadmill exercise (3.5 $km \cdot h^{-1}$) in 40°C, 30% RH. At exhaustion (69.2±11.5 min) PhSI and PeSI values peaked at 6.7±1.5 and 6.9±2.1 in an untrained ($\dot{V}O_{2peak}$; 43.6±3.8 $ml \cdot kg^{-1} \cdot min^{-1}$) population. These values are lower than the largest calculated during the fourth cycle of 40 EOD PRE (PhSI; 7.5±2.5, PeSI; 9.8±0.0) and

POST (PhSI; 6.1±0.8, PeSI; 8.4±0.7) and 20 EOD PRE (PhSI; 5.6±0.4, PeSI; 7.8±0.7) after four 16:30 (min:sec) activity cycles suggesting that during similar exposure times the mass of the EOD suit elicits a larger degree of physiological and perceptual strain than when continuous exercise is completed when an ensemble of a lighter mass was worn by thirteen male (n=10) and female (n = 3) individuals. It also highlights the potential benefits of completing this acclimation / habituation protocol observed through the reduction in strain in 20 EOD POST.

Comparing the HR and T_C changes in this study against the changes seen in other research where the clothing ensemble is worn during exposure sessions highlights that six, one hour exercise sessions (treadmill walking at 4 $km \cdot hr^{-1}$) is a sufficient stimulus to initiate a large degree of the benefits acclimation can cause. This supports Pandolf (1998) who states that 6 heat exposures causes 75% of the physiological adjustments seen. Differences in physiological and perceptual responses are visible in ambient (20°C) and hot (40°C) conditions however the largest differences are seen at a lower ambient temperature that is below T_{SK}.

5:2 Physiological Changes due to Acclimation / Habituation

5:2:1 Thermal Responses:

T_C (Figure 12.), T_{SK} (Figure 13.), heat storage (Figure 14.) and mean sweat rate (Figure 15.) were higher in EOD trials compared to NS in 40°C compared to 20°C. This may be explained by EOD suit encapsulating its wearer and reducing evaporative cooling due to a saturated microenvironment. To compensate for this large increases in T_{SK} and sweat rate, via a lowering of the T_C threshold for skin blood flow (Roberts, Wenger, Stolwijk *et al.* 1977) occur in an attempt to dissipate metabolic heat (Aoyagi, McLellan and Shephard 1998). When this is not possible heat storage occurs and T_C increases. These variables also increase by a larger magnitude in 40°C trials due to similar reasons. Additionally the high ambient temperature and gradually increasing RH (Figure 5.) insulates and contributes to heat gain (Havenith 1999). Evaporative cooling is again restricted within the PPE microenvironment as sweat does not evaporate and accumulates on the skin surface due to the rising RH (Havenith 1999). Once this happens the accumulated sweat has no cooling effect, it rolls off the skin surface and is absorbed by the clothing ensemble worn (Aoyagi, McLellan and Shephard 1998).

Acclimation / habituation caused the largest reductions in T_C, T_{SK} and heat storage in 20 EOD compared to the other conditions, however as noted to occur in other acclimation / habituation research (Cheung and McLellan 1998a) no change in mean sweat rate was observed in the current study. T_C and heat storage was also reduced following acclimation / habituation, although to a lesser magnitude in 40 EOD however T_{SK} did not differ from the PRE trial values and no changes in mean sweat rate were also observed. Therefore a larger T_C – T_{SK} thermal gradient was created POST acclimation / habituation which increased the participant's ability to store heat at a lower T_C. This again contradicts previous acclimation / habituation research that observed decreases in T_{SK} during heat-stress trials when NBC clothing was worn (McLellan and Aoyagi 1996). It is possible that because the fan system was circulating ambient temperature that was higher than T_{SK} no change in its value is noted in 40 EOD.

Absolute decreases in T_C in both these conditions are firstly due to a decrease in resting values observed following acclimation that increased heat storage capacity (Cheung and McLellan 1998a). Statistical analysis showed that changes in T_C were not different between 20 EOD PRE and 40 EOD PRE trials, however differences were observed between POST trials due to a larger reduction in 20 EOD compared to a small difference seen in 40 EOD. T_C in 40 EOD also rapidly increases from around 35 minutes after exposure (Figure 12.) due to the reduction in the heat transfer gradient between T_C-T_{SK}, which may be of interest to EOD operators when assigning safe operating times in hot environments.

Large T_C reductions in 20 EOD were accompanied with large T_{SK} reductions. This may be explained by increased heat loss efficiency via an lowering of the T_C threshold for the initiation of skin blood flow (Roberts, Wenger, Stolwijk 1997) and a decrease in heat generation due to an improved thermal response to the heat (Section 5:1) accompanied by an improved movement economy (Aoyagi, McLellan and Shephard 1997). There are several explanations for this, firstly a larger resting thermal gradient between the core and periphery was observed in POST (5.42±0.78°C) trials compared to PRE (5.30±0.51°C). A T_{SK} reduction is also possibly due to an increase in blood volume (Rowell 1974) meaning the heart worked at a lower intensity to circulate blood around the body, reflected by differences in HR values (as noted in Section 5:1). A further explanation for T_{SK} reduction in 20 EOD is the suits fan system. Once it was engaged in 20 POST it increased air movement around the suit, compared to acclimation / habituation sessions, reducing the microenvironment temperature and taking advantage of the physiological responses to heat caused by acclimation / habituation such as an increase in skin blood. However in 40 EOD trials it is possible that this fan system contributed to heat strain as it was circulating 40°C ambient air around the participant. This increased potential for heat loss in 20 EOD trials via conductive, convective and evaporative pathways benefited from the earlier increase in skin blood flow (Roberts, Wenger, Stolwijk *et al.* 1977) and other acclimation related adaptations such as a reduction in T_C responses to exercise in the heat (Cheung, McLellan 1998a). Due to this heat storage was also reduced by the largest magnitude in 20 EOD, this difference is particularly noticeable after 33 minutes (Figure 14.) of exposure. Correspondingly T_{SK} (Figure 13.) begins to plateau and T_C (Figure 12.) value does not alter implying an new equilibrium for heat loss is achieved.

Following acclimation / habituation heat storage (Figure 14.) and T_C (Figure 12.) was reduced in 40 EOD but no changes to T_{SK} (Figure 13.) and mean sweat rate (Figure 15.) were observed. These thermal changes indicate that the training protocol improved heat flow and heat loss efficiency, seen via a decrease in T_C, without increasing the temperature of the periphery or the amount of fluid lost. However as sweat rate was only calculated from body mass changes and is only an mean of 66 min rather than changes in sweat rate over smaller intervals there is the possibility that participants' sensitivity to sweat, via an earlier onset, improved as they produced larger amounts of sweat for a given T_C (Roberts, Wenger, Stolwijk et al. 1997). The consequent reduction in physiological strain due to heat stress enabled two more (n=4) participants to complete the activity sequence and increased mean tolerance time (Table 9.).

5:2:2 Cardiorespiratory Responses:

As with all thermal variables HR (Figure 16.), $\dot{V}E$ (Figure 17.) and $\dot{V}O_2$ (Figure 18) were highest in trials completed in 40°C when the EOD suit was worn. This is due to the external heat source increasing metabolic heat production due to the mass and encapsulation of the EOD suit. This amplified heat storage and cardiovascular strain and therefore the relative intensity of the activity sequence. Acclimation / habituation reduced the physiological strain of the activity sequence. The physiological strain that the heart and circulatory system was placed under to distribute blood to the periphery was reduced as participants became more efficient at dissipating heat (as noted in Section 5:1).

In accordance with previous research (McLellan and Aoyagi 1996) HR changes (Figure 16. and Table 6.) in all four conditions are lower following acclimation / habituation. However oxygen consumption (Figure 18.) was no different between the two EOD conditions prior to or following acclimation / habituation. $\dot{V}O_2$ did however decrease once acclimation / habituation was achieved, resulting in reducing metabolic heat production also indicative of a reduced sympathetic nervous response to the heat. Although oxygen consumption did not vary between EOD trials participants were able to dissipate what metabolic heat was generated more efficiently in 20 EOD due to the thermal adaptations noted (Section 5:2:1). Whether the cause of these reductions was due to participants becoming more economical when moving in the suit or more efficient at dissipating heat when sympathetic nervous activity and HR responses are lower is a debatable issue. Increasing participant's movement economy would allow them to exercise at a higher $\%\dot{V}O_{2peak}$ before the rate of lactate production exceeded the rate of clearance (lactate threshold).

When the EOD suit was worn in POST trials minute ventilation (Figure 17.) was also reduced. Reducing the rate and depth of breathing limited CO_2 production and subsequently increases plasma pH (McArdle, Katch and Katch 2000) which helped reduce the number of GSQ scores reported by participants (Table 9.) in POST compared to PRE trials. Data show that $\dot{V}E$ was reduced by the largest degree in 40 EOD (Table 6.) although it is difficult to draw a comprehensive conclusion on this issue due to the low participant numbers. These observed reductions also do not agree with findings of Aoyagi, McLellan and Shephard (1994) who report that $\dot{V}E$ increased in an untrained population when PPE was worn in the heat following acclimation. As already stated (Section 5:2:2) during their acclimation protocol participants did not wear PPE which did not allow them to become accustomed to its demands. This suggests that the $\dot{V}O_2$ and $\dot{V}E$ reductions observed in this current research were caused by participants becoming habituated to the EOD suit.

5:2:3 Physiological Strain:

PSI (Moran, Shitzer and Pandolf 1998) and PhSI (Tikuisis, McLellan and Selkirk 2002) links increases in HR and T_C to derive a figure that represents physiological strain (Section 3:5:3). Differences in these derived variables were observed between all conditions (Figure 19. and Figure 20) and reductions were also found between PRE and POST trials in all conditions apart from 40 NS (Table 6.). This is because no ‘real’ PRE to POST HR (Figure 16.) and T_C (Figure 12.)

differences were apparent in this condition. Again the condition with the largest magnitude of PRE to POST change was 20 EOD (Table 6.). The PhSI does however obtain differing results to the PSI in the 20 EOD and 40 EOD due to resting HR being replaced with a standard value (60 bt.min^{-1}) and the participants actual HR_{max} achieved throughout trials replacing a standard value of 180 bt.min^{-1} (Section 3:5:3). This resulted in a lesser reduction in calculated physiological strain values in 20 EOD and an increased reduction in 40 EOD in PhSI compared to PSI (as noted in Section 5:1).

These variations are due to the PhSI equation standardising resting HR allowing HR_{max} to rise above 180 bt.min^{-1} (Tikuisis, McLellan and Selkirk 2002). Changing this allows for a greater range of HR values to be achieved and eliminates the anticipatory rise seen in this variable before exercise is undertaken providing a more probable resting HR. For this reason the author considers this method is a more valid system of establishing physiological strain in the clothing ensemble and ambient environments used in this study.

Another advantage that the PhSI has over the PSI is that the PeSI index was developed alongside it. This perception based index has been found to show the same strain levels as its physiological counterpart during heat exposure when firefighing PPE was worn (Selkirk and McLellan 2003; Section 2:3). The only problem with this is that highly fit individuals have been shown to under perceive exertion and thermal sensation compared to physiological strain. Tikuisis, McLellan and Selkirk 2002 found that when heat stress tests were terminated untrained participants PhSI was 6.7±1.5 and PeSI was 6.9±2.1 whereas PhSI was 8.2±0.7 and PeSI was 6.1±1.7 in a trained population. However information from the present research suggests that participants over perceive physiological strain in the EOD suit in 20° and 40°C (Section 5:1). It also suggests that acclimation / habituation reduced PhSI by a larger magnitude in 20 EOD (2.9±0.4) compared to PeSI (2.6±1.2) but in 40 EOD perception of the heat declines by a larger degree than physiological responses (PeSI reduced by 1.9±0.8 compared to a PhSI reduction of 1.3±1.2; Table 6.) possibly due to participants becoming habituated to the EOD suit. This information suggests that the relationship between physiological and perceptual strain varies with ambient conditions.

<u>5:3 Perceptual Changes due to Acclimation / Habituation</u>

Although acclimation / habituation sessions were predominantly lower body exercise all whole and local (Section 3:5:5 for definitions) body segment RPE (Table 7. and Appendix D) and thermal sensation values fell and thermal comfort (Table 8. and Appendix D) values improved when the EOD suit was worn in POST trials compared to PRE (Table 6.). The highest values were recorded in 40 EOD PRE and POST trials and as with reductions observed in physiological variables (in particular T_C and HR; Section 5:1) the largest reductions in perceptual feedback, including GSQ scores (Table 9.), was observed in 20 EOD. These reductions are due to participants becoming accustomed to the microenvironment of the suit during acclimation / habituation sessions.

Possible reasons why exertive and thermal perceptions fell by such a large degree in 20 EOD is that as previously noted (Section 5:1) the suits fan system provided an external cooling device that sufficiently reduced increases in T_C (Figure 12.) once a large degree of acclimation was achieved. This fan system is also possibly the reason why perceptual strain was not reduced by the same magnitude in 40 EOD due to the 40°C ambient air circulating around the suit and contributing to the psychological discomfort associated with a heavily saturated microenvironment (Cheung, McLellan and Tenaglia 2000). Even so perceptions, including GSQ scores, did decrease following acclimation / habituation in 40 EOD which is likely to have contributed to increased tolerance times. This perceptual information supports the physiological findings demonstrating that participants were more capable of completing trials once acclimation / habituation was achieved.

PeSI (Tikuisis, McLellan and Selkirk 2002) increased over the duration of all trials and the magnitude of these increases varied between conditions (Figure 21. and Appendix D). The highest values were calculated in the final cycle of the activity sequence during 40 EOD. Acclimation / habituation reduced PeSI with the most noticeable differences seen in EOD trials. The same rationale (explained in Section 5:2:3) used to explain why acclimation / habituation did not reduce RPE and thermal sensation and increase thermal comfort by the same magnitude in 40 EOD as that seen in 20 EOD can be applied to PeSI.

Comparing PeSI levels against the equivalent physiological strain index (PhSI) suggest that participants over perceived their physical strain when wearing the EOD suit no matter of their acclimation state (Table 6. and Section 5:2:3). These data sets signify that it may be possible for PeSI and PhSI to be used during operational activities in real time to serve as an assessment of an operative's physical and psychological state although the relationship between PeSI and PhSI would need to be established on an individual basis.

5:4 Methods Rationale

HR and T_C data support the use of the 'NS' 'EOD' trial order during experimental trials as no observed differences were seen in the resting values of these two variables. They were lower prior to the commencement of POST trials however this is thought to be caused by the physiological changes initiated through acclimation / habituation. Also completing a familiarisation session dispelled any apprehension over the exercise procedure or wearing the EOD suit and the number of acclimation / habituation sessions and the exercise intensity (4 $km \cdot hr^{-1}$) used in them initiated large reductions in physiological and perceptual variables in POST trials. Additionally in the latter stages of acclimation / habituation sessions the exercise protocol elicited similar physiological and perceptual responses as those seen in 40 EOD trials (Sections 3:6, 4:1, 4:2, 4:4). The rest days that were incorporated into the protocol limited fatigue and ensured that participants commenced exercise in the same physical state on each occasion while still inducing physiological and perceptual responses associated with acclimation. Anecdotal feedback from participants supports this as they reported 'feeling tired' prior to the commencement of acclimation / habituation sessions 2, 4 and 6 and the first NS POST trial completed.

5:5 Rationale for Operative Training

The mentioned physiological and perceptual changes that occurred due to acclimation / habituation have the potential to guide training procedures and illustrate to EOD operatives that repeatedly wearing the clothing ensemble will improve their heat tolerance and induce advantageous thermoregulatory changes reducing the potential for the detrimental effects of heat strain to occur particularly in temperate conditions. The training period that this study suggests to undertake to gain these adaptations is 6, 1 hour repeated bouts of treadmill exercise whilst wearing the suit in an ambient environment (≈ 20°C). It would then be suggested that one or two training sessions a week would maintain acclimation (Pandolf, Burse and Goldman 1977) although such a study is yet to be conducted in EOD suits. This procedure can be easily be embarked upon by EOD operatives because it does not require specialist equipment to either replicate the environment or exercise procedure. Physiological and perceptual improvements that occur may also enable cognition to be improved when PPE is worn in 20° and 40°C environments (Radakovic, Maric, Surbatovic *et al.* 2007).

This study has also highlighted that acclimation / habituation in ≈ 20°C is likely to improve tolerance time and maintain performance when an EOD suit is worn in a temperate environment and that these advantageous changes are evident, although to a lesser extent, when exercise in PPE is undertaken in a hot environment. The magnitude of the thermal, metabolic and perceptual changes are found to be greater in the temperate environment suggesting that if operatives are to work in ambient surrounds similar to this they should complete repeated bouts of exercise in the clothing ensemble to become habituated to its demands. Even though smaller favourable thermoregulatory changes are observed in a hot environment (40 EOD) repeated bouts of exercise wearing the EOD suit in a temperate environment still extends heat tolerance and better maintains operational effectiveness.

6 CONCLUSION

Greater thermal, metabolic and perceptual strain is placed on participants when the EOD suit was worn and when the activity sequence was completed in 40° compared to 20°C. The acclimation / habituation protocol was a sufficient stimulus in causing heat adaptations that reduced cardiovascular and metabolic strain thus decreasing thermal and perceptual variables in all variables. In EOD trials the reduced thermal, cardiorespiratory and perceptual strain seen also suggests that the protocol increased participant's movement economy while wearing the PPE. These adaptations are also visible in 40 EOD, but to less of an extent, suggesting that acclimation / habituation in $\approx 20°C$ reduces physiological and perceptual strain in both a hot and ambient environment.

6:1 Limitations of Present Research and Areas for Future Research

The crucial limitation of this research is that it does not separate and define the individual effects of acclimation or habituation. Overall $\dot{V}O_2$ declined following acclimation / habituation possibly because of an increase in movement efficiency, reducing the need to consume oxygen and therefore metabolic heat load. Increased efficiency is seen even though acclimation / habituation sessions only used one mode of exercise where during PRE and POST trials various different upper, lower and whole body exercise were completed. Elevated HR, T_C and sweat rate during these sessions meant that participants still became accustomed to movement in the suit and its saturated microenvironment (Aoyagi, McLellan and Shephard 1998).

Physiological (T_C and HR) and psychological (RPE and thermal sensation) strain was also reduced in both 20° and 40°C NS trials. Therefore reductions cannot be fully considered to be caused by either acclimation or habituation. It is possible that during NS trials an increase in fitness caused by acclimation decreased the amount physical strain needed to complete the activity sequence (Cheung and McLellan 1998a). In EOD trials this increase in fitness combined with participants becoming habituated to the suit initiated larger reductions in physiological and psychological strain.

To distinguish between the individual effects of acclimation and habituation one of these elements needs to be removed from future investigations. To remove acclimation a heat acclimated population would need to complete a habituation protocol wearing PPE. Exercising in certain PPE examples such as an EOD suit however would raise T_C and HR sufficiently to elicit physical changes that are associated with endurance training and heat acclimation. A passive habituation protocol where participants are seated and exposed to a high ambient temperature could eliminate this. It is however unlikely that this would enable participants to become accustomed to the difficulty of moving in PPE is not at this point known.

To remove habituation participation's would need to undertake a habituation protocol or already be accustomed to wearing the PPE prior to undertaking any heat acclimation. The number of habituation exposures and the types of activities undertaken need to be addressed to establish whether an individual is 'habituated'. However exposing participants to PPE during habituation sessions may inadvertently induce physical adaptations associated with heat acclimation. So to define the extent that acclimation causes to the reduction of physiological and psychological strain a biological marker of acclimation and endurance training such as changes in blood volume over trials and changes over acclimation / habituation would need to be measured (Rowell 1974). Large increases over an entire protocol would suggest that reductions in physiological and perceptual strain are largely caused by heat acclimation, which would reduce competition between the metabolic and thermoregulatory demands when exercising in a hot environment (Rowell 1974). This increase in total blood volume would also improve sweat response and preserve blood flow to the periphery (Roberts, Wenger, Stolwijk et al. 1977).

Another limitation of this study is that it does not address whether acclimation / habituation improves and maintains cognition during EOD activities. Perceptual strain was lower during POST trials but this does not emphasise their mental capabilities before and following acclimation / habituation in either 20° or 40°C. Radakovic, Maric, Surbatovic et al. (2007) state that attention is maintained following acclimation, however problems incorporating a cognition test into experimental trials used in this research include establishing a test where no learning effect occurs and that replicates EOD activities. The test would also need to be completed over a short period of time (during the stage of physical rest; Figure 6.) and be sensitive enough to detect small changes in cognition. Such information could reiterate physiological and perceptual data that recommends that EOD operatives need to regularly undertake physical activity in the suit to improve and maintain their ability to perform functional tasks.

Another topic of operational interest is how a larger magnitude of reduction in physiological and psychological strain seen in 40 EOD can be induced. Acclimation / habituation would either need to be conducted at a higher ambient temperature or the exercise intensity would need to be increased. In doing this T_C, HR, sweat rate, RPE and thermal sensation would increase to higher levels than those observed in 40 EOD. However this protocol could severely fatigue participants, reducing capabilities to complete the activity sequence in either an ambient or a hot environment so participants would already need to have a relatively high $\dot{V}O_{2peak}$ (> 50 $ml \cdot kg^{-1} \cdot min^{-1}$).

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APPENDICIES

APPENDIX A

INFORMED CONSENT FORM

THE FACULTY OF HEALTH AND LIFE SCIENCES COVENTRY UNIVERSITY

STUDENT: MR MICHAEL ZURAWLEW

SUPERVISOR: DR. DOUG THAKE

COURSE: APPLIED PHYSIOLOGY

PROJECT TITLE: Thermal And Perceptual Responses To Simulated Explosives Ordnance Disposal Activity In Temperate And Hot Condition: The Effect Of Habituation/Acclimation

PURPOSE OF THE RESEARCH
The purpose of this study is to evaluate the efficacy of a habituation/acclimation period on the thermal and perceptual responses of subjects wearing a 35Kg. Explosives Ordnance Disposal (EOD) suit. Responses before and after the habituation/acclimation period will be measured at both 20°C and 40°C with and without the EOD suit.

PARTICIPATION IN THIS RESEARCH WILL INVOLVE
You will be required to visit the laboratory on **FOURTEEN** occasions. During six of these trials (conducted as three consecutive cycles of two days of exercise followed by a rest day) you will complete a habituation/acclimation period which will involve you wearing the EOD suit and walking on a treadmill at a low intensity for sixty minutes. Four simulated experimental trials will be completed before the acclimation period (PRE) and the final four completed following it (POST). Each set of these trials will be performed over seven days.

PROTOCOL EXAMPLE

PRE:
- Day 1 - 20°C, NO EOD SUIT
- Day 2 – DAY OFF
- Day 3 - 40°C, EOD SUIT WORN
- Day 4 – DAY OFF
- Day 5 - 40°C, NO EOD SUIT
- Day 6 – DAY OFF
- Day 7 - 20°C, EOD SUIT WORN
- Day 8- DAY OFF

A break is possible after Day 7, however POST experimental trials **MUST** directly follow acclimation sessions.

ACCLIMATION:
- Day 8 – SESSION 1
- Day 9 – SESSION 2
- Day 10 – DAY OFF
- Day 11 – SESSION 3
- Day 12 – SESSION 4

- Day 13 – DAY OFF
- Day 14 – SESSION 5
- Day 15 – SESSION 6
- Day 16 – DAY OFF

POST:
- Day 17 - 20°C, NO EOD SUIT
- Day 18 – DAY OFF
- Day 19 - 40°C, EOD SUIT WORN
- Day 20 – DAY OFF
- Day 21 - 40°C, NO EOD SUIT
- Day 22 – DAY OFF
- Day 23 - 20°C, EOD SUIT WORN

All prospective subjects will be male aged 18 to 30 years of age, healthy and free of any physical injury that would limit performance and/or cause discomfort. Additionally they will be non-smokers and have no known history of cardiorespiratory disease. Due to this project investigating the effect that a habituation/acclimation period has on thermal and perceptual responses all subjects must not have undertaken a similar exercise procedure within the last six weeks prior to testing. Also subjects are asked to ensure that they are well hydrated before every trial (which will be analysed using a urine sample) and to not to have completed any strenuous exercise that may affect this.

The first and third trials for the PRE and POST tests subjects will wear normal combat clothing, the second and fourth trials the EOD suit will be worn. A random cross over design will be applied to the temperatures (**20° or 40°C**) that subjects exercise in. During each trial the same intermittent exercise protocol will be completed, activities involved will be treadmill walking (3 min), manual loading (2 min), crawling and searching (2 min) and arm ergometry (3 min). Subjects will also be asked to rate their levels of exertion and thermal strain at certain intervals. **Each of these trials will last sixty-six minutes.** Additionally, following the 20°C trial when the EOD suit is not worn (PRE and POST) you will complete a $\dot{V}O_{2peak}$ test.

FORESEEABLE RISKS OR DISCOMFORTS

The heat strain that will be experienced through exercising in a hot environment is an obvious discomfort. Subjects may also find simple movements whilst wearing the heavy clothing ensemble uncomfortable. **When these two elements are combined the level of heat strain experienced will increase which could result in a feelings of nausea and/or dizziness.**

Other foreseeable discomforts are the blood sampling method as the skin surface is broken. 10 ml of blood will be collected via venepuncture of an antecubital vein prior to donning the suit and 5 minutes after the end or cessation of the activity cycle (which occurs sooner), a total of 20 ml per experimental trial. The facemask that will be worn to measure oxygen consumption as it restricts breathing from the nose and the thermistors that measure skin temperature that are taped to the skin surface may also cause some discomfort.

To reduce these mentioned risks, prior to every trial subjects will complete a health questionnaire and a hydration test. If subjects do not the criteria for these tests they will not be authorised to participate in any testing on that day. Also a subject's heart rate, core temperature and skin temperature will be continually monitored and perceptual questions will be posed to the subject at certain intervals. If at any point the safety parameters are exceeded, a trial will be terminated.

BENEFITS TO THE SUBJECT OF PARTICIPATION

Through participating in the study subjects will have their anthropometric measurements taken and body composition estimated (body fat percentage and muscle mass). Participation in the study should also be seen as a physical challenge, so successfully completing trials should have some rewarding benefits. Finally there is the possibility that this investigation could either be used by subjects in addition to an existing fitness regime or enable them to improve their fitness levels through the physiological adaptations that occur via the habituation/acclimation process.

WHAT WILL HAPPEN TO YOUR DATA

Any data/results from your participation in the study will be used by Michael Zurawlew as part of his thesis. The data will also be available to Doug Thake and the students sponsor, NP Aerospace. It may also be published in scientific works, but your name or identity will not be revealed. Data that connects a subject's name to their results will be kept in a locked filing cabinet. Any personal data held on computer will be held in password protected files on a password protected computer. Following each experimental session and at the end of the entire investigation the student, Michael Zurawlew, will explain the implications of the subject's results to him.

Content removed on data protection grounds

If you have any questions about your rights as a participant or feel you have been placed at risk you can contact Dr. Doug Thake.

I confirm that I have read the above information. The nature, demands and risks of the project have been explained to me. I have also been informed of any benefits to me from participation.

I knowingly assume the risks involved and understand that I may withdraw my consent and discontinue participation at any time without penalty and without having to give any reason.

Subject's signature ______________________________________Date _____________

Investigator's signature _________________________________ Date _____________

The signed copy of this form is retained by the student, and at the end of the project passed on to the supervisor. A second copy of the consent form should be given to the subject for them to keep for their own reference.

APPENDIX B

	DAY NUMBER	ACTIVITY / REST DAY UNDERTAKEN
PRE TRIALS	1	20°C, NO EOD SUIT
	2	*REST DAY*
	3	40°C, EOD SUIT WORN
	4	*REST DAY*
	5	40°C, NO EOD SUIT WORN
	6	*REST DAY*
	7	20°C, EOD SUIT WORN
	8	*REST DAY*
ACCLIMATION / HABITUATION	9	SESSION 1
	10	SESSION 2
	11	*REST DAY*
	12	SESSION 3
	13	SESSION 4
	14	*REST DAY*
	15	SESSION 5
	16	SESSION 6
	17	*REST DAY*
POST TRIALS	18	20°, NO EOD SUIT WORN
	19	*REST DAY*
	20	40°C, EOD SUIT WORN
	21	*REST DAY*
	22	40°C, NO EOD SUIT WORN
	23	*REST DAY*
	24	20°C EOD SUIT WORN

Figure 22. An example of the pattern experimental trials and acclimation sessions were completed.

APPENDIX C

6	NO EXERTION
7	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

Figure 23. Example of Rating of Perceived Exertion (RPE) scale and verbal anchors (Borg 1970).

0.0	UNBEARABLY COLD
1.0	VERY COLD
2.0	COLD
3.0	COOL
4.0	COMFORTABLE
5.0	WARM
6.0	HOT
7.0	VERY HOT
8.0	UNBEARABLY HOT

Figure 24. Example of perceived thermal sensation scale and verbal anchors (Young, Sawka, Epstein *et al*. 1987).

0.0	VERY UNCOMFORTABLY COLD
1.0	UNCOMFORTABLY COLD
2.0	SLIGHTY UNCOMFORTABLY COLD
3.0	
4.0	COMFORTABLE
5.0	
6.0	SLIGHTLY UNCOMFORTABLY HOT
7.0	UNCOMFORTABLY HOT
8.0	VERY UNCOMFORTABLY HOT

Figure 25. Example of adapted perceived thermal comfort scale and verbal anchors (Epstein and Moran 2006).

Headache:	0	None at all
	1	Mild
	2	Moderate
	3	Severe
Sickness	0	None at all
	1	Mild
	2	Moderate
	3	Severe
Dizziness/ Light-headedness	0	None at all
	1	Mild
	2	Moderate
	3	Severe
Mentally Confused	0	None at all
	1	Mild
	2	Moderate
	3	Severe
Tiredness	0	None at all
	1	Mild
	2	Moderate
	3	Severe
Difficulty Breathing	0	None at all
	1	Mild
	2	Moderate
	3	Severe

Figure 26. Example of General Symptoms Questionnaire (GSQ) scales and verbal anchors (Thake 2006).

APPENDIX D

Table 11. Overall and local body segment thermal sensation, thermal comfort and RPE scores in 20 NS PRE and POST. Values are mean±SD. Main effects for condition are annotated as; *** (P≤0.001). Differences PRE to POST acclimation / habituation compared within the same condition located via Tukey post hoc tests are annotated as $^{\#}$ (P≤0.05), $^{\#\#}$ (P≤0.01), $^{\#\#\#}$ (P≤0.001).

	Stage	Thermal Sensation					Thermal Comfort					RPE			
		Overall***	Back***	Chest & arms***	Groin***	Legs***	Overall***	Back***	Chest & arms***	Groin***	Legs***	Overall***	Upper back & shoulders***	Lower back***	Legs***
20 No Suit PRE	1	4.0±0.9	3.8±0.8	3.8±0.8	3.7±0.5	3.7±0.5	4.0±0.6	4.0±0.6	4.0±0.6	3.8±0.4	3.8±0.4	7.2±0.4	7.2±0.8	7.0±0.7	7.4±0.9
	2	3.8±0.8	4.0±0.9	3.8±0.8	3.8±0.8	4.0±0.9	4.0±0.6	4.0±0.6	4.0±0.6	4.0±0.6	4.0±0.6	8.5±0.5	8.3±0.8	7.8±0.8	8.0±0.9
	3	4.0±0.9	4.0±0.9	4.0±1.1	4.0±0.9	4.0±0.9	4.0±0.6	4.2±0.8	4.2±1.0	4.0±0.6	4.2±0.8	8.0±1.1	7.8±1.2	7.7±0.8	8.2±1.2
	4	4.2±1.2	4.2±1.2	4.0±1.1	3.8±0.8	4.0±0.9	4.2±1.0	4.3±1.0	4.2±1.0	4.0±0.6	4.0±0.6	9.3±0.8	8.8±1.3	8.5±1.0	8.7±1.2
	5	4.2±1.2	4.2±1.2	4.0±1.1	3.8±0.8	4.0±0.9	4.3±1.0	4.3±1.0	4.2±1.0	4.0±0.6	4.2±0.8	8.8±1.5	8.8±1.5	8.5±1.2	8.7±1.4
	6	4.0±1.1	4.2±1.2	4.0±1.1	3.8±0.8	4.0±0.9	4.2±1.0	4.3±1.0	4.2±1.0	4.0±0.6	4.0±0.6	9.2±1.5	9.0±1.4	8.8±1.5	9.0±1.5
	7	4.2±1.2	4.3±1.2	4.0±1.1	3.8±0.8	4.0±0.9	4.3±1.0	4.3±1.0	4.2±1.0	4.0±0.6	4.2±0.8	8.8±1.6	9.0±1.8	8.7±1.5	9.0±1.7
	8	4.0±1.1	4.3±1.2	4.0±1.1	3.8±0.8	4.0±0.9	4.2±1.0	4.3±1.0	4.2±1.0	4.0±0.6	4.0±0.6	9.3±1.6	8.8±1.5	8.7±1.4	9.0±1.5
20 No Suit POST	1	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	7.0±0.9	7.0±0.9	6.7±0.8	7.0±0.9
	2	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	7.2±1.0	7.2±1.0	6.8±1.0	7.2±1.0
	3	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.7±0.8	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	7.3±1.0	7.3±1.0	6.8±0.8	7.3±0.8
	4	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	7.5±1.0	7.5±1.0	7.0±0.9	7.3±0.8
	5	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	7.7±1.4	7.5±1.4	7.0±0.6	7.5±1.4
	6	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	8.0±1.7	7.8±1.7	7.2±0.8	7.5±1.4
	7	3.5±0.5	3.5±0.5	3.5±0.5	3.5±0.5	3.7±0.8	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	3.7±0.5	7.8±1.3	7.7±1.4	7.2±0.8	7.7±1.4
	8	3.5±0.5$^{\#\#\#}$	3.5±0.5$^{\#\#\#}$	3.5±0.5$^{\#}$	3.5±0.5$^{\#\#\#}$	3.7±0.8$^{\#\#\#}$	3.7±0.5$^{\#}$	3.7±0.5$^{\#\#\#}$	3.7±0.5$^{\#}$	3.7±0.5	3.7±0.5	8.0±1.7$^{\#\#}$	7.8±1.7$^{\#}$	7.2±0.8$^{\#\#\#}$	7.5±1.4$^{\#\#}$

Table 12. Overall and local body segment thermal sensation, thermal comfort and RPE scores in 20 EOD PRE and POST. Values are mean±SD. Main effects for condition are annotated as; *** ($P \leq 0.001$). Differences PRE to POST acclimation / habituation compared within the same condition located via Tukey post hoc tests are annotated as ### ($P \leq 0.001$).

	Stage	Thermal Sensation					Thermal Comfort					RPE			
		Overall***	Back***	Chest & arms***	Groin***	Legs***	Overall***	Back***	Chest & arms***	Groin***	Legs***	Overall***	Upper back & shoulders***	Lower back***	Legs***
20 EOD PRE	1	5.3±0.5	5.7±0.8	5.7±0.8	5.2±0.4	4.8±1.5	5.7±0.5	5.0±1.0	5.0±0.9	5.0±0.6	4.8±1.0	10.8±1.5	12.3±1.0	11.3±0.8	11.3±1.4
	2	5.2±0.8	5.3±1.0	5.2±0.4	5.0±0.6	4.7±0.8	5.2±1.0	5.0±1.0	5.0±0.6	4.7±0.5	4.5±0.8	12.7±1.0	13.7±1.2	12.3±0.8	11.3±1.0
	3	6.2±0.4	6.2±0.8	5.8±0.4	5.7±0.5	5.8±0.4	6.0±0.6	6.0±1.0	5.7±0.8	5.3±0.8	5.7±0.5	12.8±0.8	13.8±1.3	12.5±1.0	11.8±0.8
	4	5.5±0.8	5.8±1.2	5.5±0.8	5.5±0.5	5.2±1.0	5.7±0.5	6.0±1.0	5.8±0.4	5.2±0.8	5.2±0.8	13.0±0.6	14.5±1.4	12.8±1.3	12.3±1.2
	5	6.3±0.5	6.5±0.8	6.2±0.8	5.8±0.4	5.7±0.8	6.3±1.0	6.0±0.8	6.2±0.5	5.7±0.5	5.5±1.2	13.7±1.6	14.2±1.6	13.2±1.3	12.5±1.1
	6	6.2±0.8	6.3±0.8	6.2±0.8	5.8±0.4	5.7±0.8	6.2±1.0	6.0±0.8	6.2±0.5	5.7±0.5	5.5±1.5	14.5±1.9	15.5±1.9	13.2±1.3	13.2±1.3
	7	6.8±0.4	6.7±0.8	6.7±0.5	6.0±0.6	6.0±0.4	6.8±1.0	7.0±0.8	6.5±0.8	6.2±0.9	6.0±2.3	14.5±2.4	15.3±2.4	13.8±1.3	13.0±1.6
	8	6.7±0.8	6.7±0.8	6.5±0.8	6.0±0.6	6.2±0.8	6.7±1.0	7.0±0.8	6.5±0.8	6.2±0.8	6.2±1.8	15.5±1.8	16.3±2.3	14.2±1.7	13.2±1.8
20 EOD POST	1	4.0±0.6	4.0±0.6	3.8±0.4	4.0±0.6	4.0±0.6	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	9.7±2.3	10.3±2.5	8.7±1.6	9.3±2.4
	2	4.2±0.4	4.2±0.4	4.0±0.0	4.2±0.4	4.2±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	3.8±0.4	10.0±1.7	11.0±2.1	9.3±1.0	9.2±1.2
	3	4.7±0.5	4.5±0.5	4.5±0.5	4.3±0.5	4.5±0.5	4.5±0.5	4.3±0.5	4.3±0.5	4.3±0.5	4.3±0.5	10.3±2.0	11.0±2.1	9.5±1.5	10.3±2.6
	4	4.3±0.5	4.3±0.5	4.2±0.4	4.2±0.4	4.2±0.4	4.0±0.0	4.0±0.0	4.0±0.0	4.0±0.0	4.0±0.0	11.0±1.9	11.5±2.3	10.0±1.3	10.3±1.6
	5	4.8±0.8	5.0±0.9	4.7±0.5	4.5±0.5	4.8±0.8	4.8±0.8	4.8±1.0	4.7±0.5	4.8±0.8	4.8±0.8	11.3±1.9	12.0±2.0	10.2±1.2	10.8±2.3
	6	4.3±0.5	4.5±0.8	4.3±0.5	4.3±0.5	4.3±0.5	4.3±0.5	4.5±0.8	4.2±0.4	4.3±0.5	4.3±0.5	11.7±1.8	12.5±2.2	10.7±1.4	11.3±2.2
	7	4.8±0.8	5.2±0.8	4.8±0.8	4.7±0.8	4.8±0.8	4.7±0.8	5.0±0.9	4.8±0.8	4.5±0.5	4.8±0.8	12.0±2.2	12.7±2.3	11.0±1.6	11.0±1.9
	8	4.3±0.5###	4.7±0.8###	4.7±0.8###	4.3±0.6###	4.3±0.5###	4.5±0.8###	4.7±1.0###	4.5±0.8###	4.3±0.5###	4.3±0.5###	12.0±2.1###	13.0±2.6###	11.0±1.6###	11.0±2.1###

Table 13. Overall and local body segment thermal sensation, thermal comfort and RPE scores in 40 NS PRE and POST. Values are mean±SD. Main effects for condition are annotated as; *** ($P \leq 0.001$). Differences PRE to POST acclimation / habituation compared within the same condition located via Tukey post hoc tests are annotated as $^{\#}$ ($P \leq 0.05$), $^{\#\#}$ ($P \leq 0.01$), $^{\#\#\#}$ ($P \leq 0.001$).

	Stage	Thermal Sensation					Thermal Comfort					RPE			
		Overall***	Back***	Chest & arms***	Groin***	Legs***	Overall***	Back***	Chest & arms***	Groin***	Legs***	Overall***	Upper back & shoulders***	Lower back***	Legs***
40 No Suit PRE	**1**	5.0±0.6	4.8±0.4	4.8±0.8	4.7±0.5	4.5±0.5	4.8±0.8	5.0±1.0	4.7±0.8	4.5±0.5	4.3±0.5	7.5±1.2	7.2±1.2	7.3±1.4	7.7±2.1
	2	4.7±0.8	4.7±0.8	4.8±1.0	4.7±0.8	4.5±0.8	4.7±0.8	5.0±1.0	4.8±1.0	4.5±0.8	4.5±0.8	8.5±0.8	8.5±0.8	8.3±1.2	8.3±1.0
	3	5.5±0.5	5.5±0.5	5.3±1.2	5.2±0.8	5.2±0.8	5.3±0.8	5.0±1.0	5.2±1.3	5.0±0.9	5.0±0.9	9.2±2.0	8.8±1.7	8.5±1.8	9.3±2.3
	4	5.2±1.0	5.3±0.8	5.2±1.3	4.8±1.0	4.8±1.0	5.5±1.4	6.0±1.0	5.3±1.5	5.2±1.5	5.2±1.5	10.0±1.8	9.8±1.8	9.2±2.0	9.2±2.0
	5	5.8±0.8	5.8±0.8	5.5±1.1	5.5±0.8	5.2±0.8	5.8±1.2	6.0±1.0	5.7±1.2	5.7±1.0	5.3±1.0	10.0±2.1	9.7±2.3	9.2±2.3	9.8±2.0
	6	6.2±0.8	5.8±0.8	5.5±1.1	5.7±0.8	5.5±0.8	6.2±1.0	6.0±1.0	5.8±1.3	5.8±1.0	5.5±1.0	10.5±2.2	10.3±2.4	9.5±2.6	9.7±2.3
	7	6.2±0.8	6.0±0.6	5.8±1.0	5.7±0.8	5.7±0.8	6.2±1.2	6.0±1.0	5.7±1.2	5.5±0.8	5.3±0.8	10.7±2.2	10.2±2.6	9.7±2.6	10.2±2.5
	8	6.0±0.6	6.0±0.6	5.5±0.8	5.7±0.8	5.5±0.8	6.0±1.1	6.0±1.0	5.7±1.2	5.7±0.8	5.7±0.8	11.0±2.5	10.8±3.1	10.0±3.4	10.2±2.5
40 No Suit POST	**1**	4.5±0.5	4.3±0.5	4.5±0.5	4.3±0.5	4.2±0.4	4.2±0.4	4.2±0.4	4.2±0.4	4.2±0.4	4.2±0.4	8.2±1.7	7.8±1.7	7.2±1.5	8.3±2.3
	2	4.8±0.4	4.8±0.4	4.8±0.8	4.7±0.5	4.7±0.5	4.2±0.4	4.2±0.4	4.2±0.4	4.2±0.4	4.2±0.4	8.2±1.7	8.2±1.7	7.5±1.2	8.0±1.5
	3	5.3±0.5	5.2±0.4	5.2±0.4	5.2±0.4	5.0±0.6	4.7±0.5	4.5±0.5	4.5±0.5	4.5±0.5	4.5±0.5	8.3±1.5	8.0±1.5	7.5±1.2	8.7±1.9
	4	5.2±0.4	5.0±0.0	4.8±0.4	5.0±0.0	5.0±0.0	4.7±0.5	4.7±0.5	4.5±0.5	4.7±0.5	4.5±0.5	8.8±1.9	8.5±2.0	7.7±1.2	8.5±2.0
	5	5.5±0.5	5.5±0.5	5.3±0.5	5.3±0.5	5.3±0.5	5.0±0.9	5.0±0.9	5.0±0.6	5.0±0.9	5.0±0.9	9.2±2.1	8.5±2.3	7.8±1.5	8.8±2.2
	6	5.2±0.4	5.2±0.4	5.0±0.6	5.2±0.4	5.2±0.4	5.0±0.9	5.0±0.9	4.8±0.8	5.0±0.9	5.0±0.9	9.3±2.3	8.8±2.2	8.0±1.1	8.7±2.3
	7	5.5±0.5	5.3±0.5	5.3±0.5	5.3±0.5	5.3±0.5	5.2±0.8	5.0±0.9	5.0±0.6	5.0±0.9	5.0±0.9	9.2±2.1	8.8±2.4	8.2±1.3	9.2±2.4
	8	5.2±0.4$^{\#}$	5.2±0.4$^{\#\#}$	5.0±0.6	5.2±0.4	5.2±0.4	4.8±0.8$^{\#\#\#}$	4.8±0.8$^{\#\#\#}$	4.8±0.8$^{\#\#\#}$	4.8±0.8$^{\#\#\#}$	4.8±0.8$^{\#}$	9.5±2.3	9.0±2.2	8.0±1.1$^{\#\#\#}$	8.8±2.2

Table 14. Overall and local body segment thermal sensation, thermal comfort and RPE scores in 40 EOD PRE and POST. Values are mean±SD. Main effects for condition are annotated as; *** ($P \leq 0.001$). Differences PRE to POST acclimation / habituation compared within the same condition located via Tukey post hoc tests are annotated as ### ($P \leq 0.001$).

	Stage	Thermal Sensation					Thermal Comfort					RPE			
		Overall***	Back***	Chest & arms***	Groin***	Legs***	Overall***	Back***	Chest & arms***	Groin***	Legs***	Overall***	Upper back & shoulders***	Lower back***	Legs***
40 EOD Suit PRE	1	6.0±0.6	6.0±0.6	6.0±1.0	6.0±1.0	6.0±1.0	6.0±1.0	6.0±0.0	6.0±1.0	6.0±1.0	6.0±1.0	12.0±1.0	13.0±1.1	11.0±1.0	11.0±1.0
	2	5.8±0.8	5.8±0.8	6.0±1.0	6.0±1.0	6.0±1.0	6.0±1.0	6.0±0.0	6.0±1.0	6.0±1.0	6.0±1.0	13.0±.1.0	13.8±1.7	12.0±1.0	12.0±1.0
	3	6.8±0.4	6.7±0.5	7.0±1.0	6.0±0.0	7.0±1.0	7.0±1.0	7.0±1.0	7.0±1.0	6.0±1.0	7.0±1.0	14.0±2.0	14.2±2.1	13.0±2.0	13.0±1.0
	4	6.7±0.5	6.7±0.5	6.0±1.0	6.0±1.0	6.0±1.0	7.0±1.0	7.0±1.0	7.0±1.0	7.0±1.0	7.0±1.0	15.0±2.0	15.5±2.1	13.0±2.0	13.0±1.0
	5	7.0±0.0	7.0±0.0	7.0±1.0	7.0±1.0	6.0±1.0	7.0±1.0	7.0±1.0	7.0±1.0	7.0±0.0	7.0±1.0	16.0±1.0	16.3±2.0	14.0±2.0	14.0±2.0
	6	7.0±0.0	7.0±0.0	7.0±1.0	7.0±1.0	7.0±1.0	7.0±1.0	7.0±1.0	7.0±1.0	7.0±0.0	7.0±0.0	17.0±1.0	17.5±1.0	15.0±2.0	15.0±2.0
	7	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	18.0±1.0	18.3±1.2	16.0±3.0	15.0±3.0
	8	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	8.0±0.0	19.0±0.0	19.3±0.6	16.0±2.0	16.0±2.0
40 EOD POST	1	5.2±0.4	5.0±0.0	5.0±0.6	4.8±0.4	4.8±0.4	5.2±0.4	5.0±0.0	5.0±0.6	4.8±0.4	4.7±0.5	9.8±1.2	10.5±1.6	9.0±1.4	9.3±2.1
	2	5.0±0.0	5.0±0.0	4.8±0.4	4.8±0.4	4.8±0.4	4.8±0.4	4.8±0.4	4.8±0.4	4.8±0.4	4.7±0.5	10.5±1.4	10.8±1.7	9.3±1.8	9.3±2.5
	3	5.8±0.4	5.7±0.5	5.5±0.8	5.3±0.5	5.7±0.5	5.7±0.5	5.5±0.5	5.5±0.8	5.3±0.5	5.5±0.5	10.8±1.7	11.3±1.5	9.5±1.6	9.8±2.8
	4	5.7±0.5	5.7±0.5	5.5±0.8	5.5±0.5	5.3±0.5	5.7±0.5	5.7±0.5	5.5±0.8	5.5±0.5	5.3±0.5	12.0±1.7	12.3±1.5	9.8±2.0	10.5±2.5
	5	6.0±0.0	6.4±0.5	5.8±0.4	6.0±0.0	5.8±0.4	6.0±0.0	6.4±0.5	5.8±0.4	5.8±0.4	5.8±0.4	12.5±1.2	13.3±1.6	10.7±1.8	11.5±2.3
	6	6.2±0.4	6.6±0.5	6.0±0.7	6.2±0.4	6.0±0.7	6.2±0.4	6.6±0.5	6.0±0.7	6.2±0.4	6.0±0.7	14.4±1.9	14.6±1.8	11.8±1.9	12.2±2.4
	7	7.0±0.0	7.0±0.0	6.8±0.5	7.0±0.0	7.0±0.0	7.0±0.0	7.0±0.0	6.5±1.0	6.8±0.5	6.8±0.5	15.6±1.7	15.4±1.5	13.0±2.7	14.0±3.5
	8	6.8±1.0###	7.0±0.8###	6.5±1.3###	6.8±1.0###	6.8±1.0###	6.8±1.0###	7.0±0.8###	6.8±1.0###	6.8±1.0###	6.8±1.0###	16.8±1.9###	17.0±2.0###	13.5±3.7###	14.5±4.4###

Table 15. Perception based strain index measured at the arm ergometry stage of each cycle during the simulated activity sequence. Values are mean±SD. Main effects for condition $P \leq 0.001$. Differences PRE to POST acclimation / habituation compared within the same condition located via Tukey post hoc tests are annotated as # ($P \leq 0.05$), ### ($P \leq 0.001$).

Condition	**Cycle**			
	1	**2**	**3**	**4**
20 No Suit PRE	2.0±0.9	2.3±1.1	2.4±1.4	2.5±1.5
20 No Suit POST###	1.0±0.7	1.2±0.8	1.3±1.0	1.3±1.0
20 EOD PRE	4.8±0.7	5.7±0.5	6.4±0.9	7.3±0.7
20 EOD POST###	2.5±1.1	3.5±1.1	3.9±1.3	4.1±1.4
40 No Suit PRE	3.0±0.9	4.0±1.0	4.5±1.3	5.0±1.5
40 No Suit POST#	2.4±0.9	3.4±1.1	3.8±1.2	3.8±0.9
40 EOD PRE	5.6±1.1	7.0±0.7	8.0±0.3	9.6±0.0
40 EOD POST###	3.9±0.7	5.0±0.6	6.1±0.7	7.9±0.7